November, 1946
Volume 50, No. 5

Metal Progress

Ernest E. Thum, Editor

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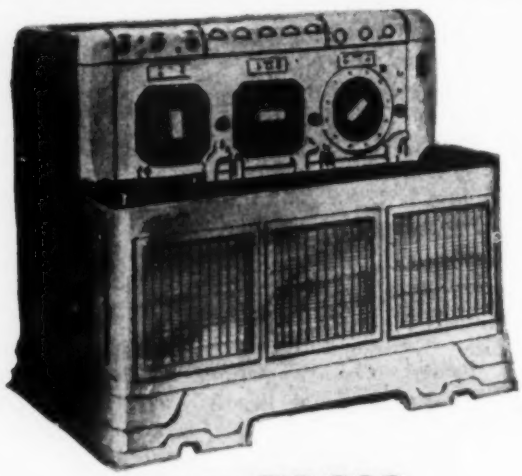
FOR A BETTER JOB

MODERN INDUCTION HARDENERS



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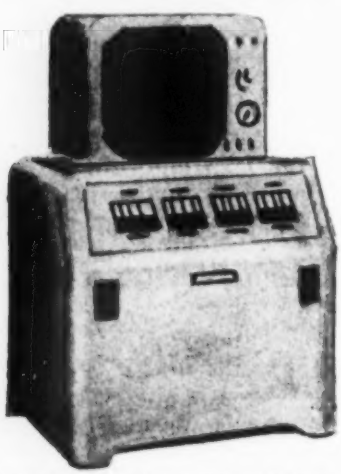

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700-3

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CONSOLIDATED PROGRAM

National Metal Congress

AMERICAN SOCIETY FOR METALS

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS (A.I.M.E.)

AMERICAN WELDING SOCIETY (A.W.S.)

AMERICAN INDUSTRIAL RADIUM AND X-RAY SOCIETY (X-Ray)

Monday, Nov. 18, 1946

9:30 A.M. A.W.S. Session on Weldability; Hotel Ambassador

9:30 A.M. A.W.S. Session on Electrodes; Hotel Ambassador

9:30 A.M. A.W.S. Railroad Session; Hotel Ambassador

10:00 A.M. Session on High-Temperature Alloys; Municipal Auditorium

10:00 A.M. Session on Magnesium Alloys; Municipal Auditorium

10:00 A.M. Session on Stainless Steel; Municipal Auditorium

10:00 A.M. A.I.M.E. (Iron and Steel Division) General Session, Hotel Claridge

10:30 A.M. A.I.M.E. (Institute of Metals Division) Session on Aluminum Alloys; Hotel Claridge

12:00 M. National Metal Exposition opens; Municipal Auditorium

12:30 P.M. A.I.M.E. (Institute of Metals Division) Executive Committee Luncheon and Meeting; Hotel Claridge

2:00 P.M. Session on Steelmaking; Auditorium

2:00 P.M. Session on Nonferrous Alloys; Municipal Auditorium

2:00 P.M. Lecture Course on Sleeve Bearing Metals; Municipal Auditorium

2:00 P.M. A.I.M.E. (Iron and Steel and Institute of Metals Divisions) Joint Session on Magnesium Alloys and Oxide Films; Hotel Claridge

2:00 P.M. A.I.M.E. (Iron and Steel Division) Session on Metallography; Hotel Claridge

2:00 P.M. A.W.S. Session on Research; Ambassador

2:00 P.M. A.W.S. Session on Production; Ambassador

2:00 P.M. A.W.S. Session on Storage Tanks and Pressure Vessels; Hotel Ambassador

3:00 P.M. Lecture Course on Electronic Methods of Inspection of Metals; Municipal Auditorium

8:00 P.M. Lecture Course on Sleeve Bearing Metals; Municipal Auditorium

8:00 P.M. Lecture Course on Physical Metallurgy of Aluminum; Municipal Auditorium

8:00 P.M. A.W.S. Adams Lecture; Hotel Ambassador

10:30 P.M. National Metal Exposition closes

Tuesday, Nov. 19, 1946

9:00 A.M. A.I.M.E. (Iron and Steel and Institute of Metals Divisions) Joint Symposium on Effects of Multiaxial Stresses on Metals; Hotel Claridge

9:30 A.M. A.W.S. Session on Research; Hotel Ambassador

9:30 A.M. A.W.S. Session on Resistance Welding; Hotel Ambassador

9:30 A.M. A.W.S. Session on Machinery; Hotel Ambassador

10:00 A.M. Session on Heat Treatment of Toolsteels; Municipal Auditorium

10:00 A.M. Session on Crystal Structure; Municipal Auditorium

10:00 A.M. Session on Iron Alloys; Municipal Auditorium

10:45 A.M. A.I.M.E. (Institute of Metals Division) Annual Lecture; Hotel Claridge

12:00 M. National Metal Exposition opens; Municipal Auditorium

12:30 P.M. A.I.M.E. (Iron and Steel Division) Executive Committee Luncheon and Meeting; Hotel Claridge

2:00 P.M. Session on Physical Properties and Testing; Municipal Auditorium

2:00 P.M. Session on Temper Brittleness; Municipal Auditorium

2:00 P.M. Lecture Course on Sleeve Bearing Metals; Municipal Auditorium

2:00 P.M. A.I.M.E. (Iron and Steel and Institute of Metals Divisions) Joint Symposium on Effects of Multiaxial Stresses on Metals; Hotel Claridge

2:00 P.M. A.I.M.E. (Institute of Metals Division) General Session; Hotel Claridge

2:00 P.M. A.W.S. Session on Research; Hotel Ambassador

2:00 P.M. A.W.S. Session on Resistance Welding; Hotel Ambassador

2:00 P.M. A.W.S. Session on Shipbuilding; Hotel Ambassador

3:00 P.M. Lecture Course on Electronic Methods of Inspection of Metals; Municipal Auditorium

5:30 P.M. A.I.M.E. (Iron and Steel and Institute o Metals Divisions) Cocktail Party; Hotel Claridge

6:30 P.M. A.I.M.E. Annual Fall Dinner; Hotel Claridge

Tuesday Evening

8:00 P.M. ⊜ Lecture Course on Sleeve Bearing Metals; Municipal Auditorium

8:00 P.M. ⊜ Lecture Course on Physical Metallurgy of Aluminum; Municipal Auditorium

8:00 P.M. A.W.S. University Research Conference; Hotel Ambassador

10:30 P.M. National Metal Exposition Closes

Wednesday, Nov. 20, 1946

7:30 A.M. ⊜ Chapter Chairmen's Breakfast; Hotel Traymore

8:30 A.M. Industrial Gas Breakfast; Hotel Traymore

9:30 A.M. A.W.S. Session on Cutting; Hotel Ambassador

9:30 A.M. A.W.S. Session on Resistance Welding; Hotel Ambassador

9:30 A.M. A.W.S. Structural Session; Hotel Ambassador

9:30 A.M. X-Ray Session on Quantitative Measurement of Penetrating Radiation; Seaside Hotel

10:00 A.M. ⊜ Annual Meeting and Campbell Memorial Lecture; Municipal Auditorium

12:00 M. National Metal Exposition opens

12:00 M. ⊜ Canadian Luncheon; Hotel Traymore

12:00 M A.I.M.E. (Iron and Steel Division) Physical Chemistry of Steelmaking Committee Luncheon; Hotel Claridge

2:00 P.M. ⊜ Session on Heat Resisting Alloys; Municipal Auditorium

2:00 P.M. ⊜ Session on Research and Inspection; Municipal Auditorium

2:00 P.M. ⊜ Lecture Course on Sleeve Bearing Metals; Municipal Auditorium

2:00 P.M. A.I.M.E. (Institute of Metals Division) Session on Copper Alloys and Metallography; Hotel Claridge

2:00 P.M. A.I.M.E. (Institute of Metals) Powder Metallurgy Committee Meeting; Hotel Claridge

2:00 P.M. A.W.S. Session on Resistance Welding; Hotel Ambassador

2:00 P.M. A.W.S. Session on Cutting; Hotel Ambassador

2:00 P.M. A.W.S. Session on Welding Alloy Steels; Hotel Ambassador

2:00 P.M. X-Ray Session on Commercial and Research Applications of Radiography; Seaside Hotel

2:30 P.M. A.I.M.E. (Iron and Steel Division) Session on Physical Chemistry of Blast Furnace and Openhearth; Hotel Claridge

3:00 P.M. ⊜ Lecture Course on Electronic Methods of Inspection of Metals; Municipal Auditorium

4:00 P.M. A.S.T.M. Subcommittee 6 of Committee B-2 Meeting; Municipal Auditorium

6:30 P.M. A.W.S. Section Officers Dinner; Hotel Ambassador

8:00 P.M. A.W.S. Section Activities Meeting; Hotel Ambassador

8:00 P.M. ⊜ Lecture Course on Physical Metallurgy of Aluminum; Municipal Auditorium

8:00 P.M. ⊜ Lecture Course on Structure of Cast Iron; Municipal Auditorium

10:30 P.M. National Metal Exposition closes

Thursday, Nov. 21, 1946

9:30 A.M. A.W.S. Session on Pressure Welding; Hotel Ambassador

9:30 A.M. A.W.S. Session on Aircraft; Hotel Ambassador

9.30 A.M. A.W.S. Session on Hard Facing; Hotel Ambassador

9:30 A.M. X-Ray Session on Radiation Methods for Fine Structure Analysis; Seaside Hotel

10:00 A.M. National Metal Exposition opens

10:00 A.M. ⊜ Session on Transformation of Austenite; Municipal Auditorium

10:00 A.M. ⊜ Session on Copper Alloys; Municipal Auditorium

10:00 A.M. ⊜ Session on Steelmaking; Municipal Auditorium

12:00 M. College Alumni Luncheons; Hotel Traymore

2:00 P.M. ⊜ Session on Hardness and Hardenability; Municipal Auditorium

2:00 P.M. ⊜ Session on Physical Properties; Municipal Auditorium

2:00 P.M. ⊜ Lecture Course on Structure of Cast Iron; Municipal Auditorium

2:00 P.M. X-Ray Annual Meeting and Mehl Lecture; Seaside Hotel

3:00 P.M. ⊜ Lecture Course on Electronic Methods of Inspection of Metals; Municipal Auditorium

4:00 P.M. ⊜ Lecture Course on Physical Metallurgy of Aluminum; Municipal Auditorium

6:00 P.M. National Metal Exposition closes

7:00 P.M. ⊜ Annual Banquet; Hotel Traymore

7:00 P.M. A.W.S. Dinner; Hotel Ambassador

Friday, Nov. 22, 1946

9:30 A.M. A.W.S. Session on High Alloys; Hotel Ambassador

9:30 A.M. A.W.S. Miscellaneous Session; Hotel Ambassador

9:30 A.M. A.W.S. Miscellaneous Session; Hotel Ambassador

9:30 A.M. X-Ray Session on Technique and Diagnosis Standardization; Seaside Hotel

10:00 A.M. National Metal Exposition opens

10:00 A.M. ⊜ Session on Carburizing; Municipal Auditorium

10:00 A.M. ⊜ Session on Microstructure; Municipal Auditorium

10:00 A.M. ⊜ Session on Cast Steels; Municipal Auditorium

2:00 P.M. ⊜ Session on Hydrogen Embrittlement; Municipal Auditorium

2:00 P.M. ⊜ Lecture Course on Structure of Cast Iron; Municipal Auditorium

2:00 P.M. ⊜ Lecture Course on Electronic Methods of Inspection of Metals; Municipal Auditorium

2:00 P.M. ⊜ Lecture Course on Physical Metallurgy of Aluminum; Municipal Auditorium

2:00 P.M. X-Ray Session on Nondestructive or Allied Test Methods; Seaside Hotel

2:00 P.M. A.W.S. Business Meeting; Hotel Ambassador

3:00 P.M. A.W.S. Board of Directors Meeting; Hotel Ambassador

6:00 P.M. National Metal Congress and National Metal Exposition ends.

Technical Meetings

Simultaneous Morning and Afternoon Sessions in Municipal Auditorium

Monday, Nov. 18—10:00 A. M.

High-Temperature Alloys

BALLROOM, MUNICIPAL AUDITORIUM

The Development of a Turbosupercharger Bucket Alloy, by E. Epremian, Rensselaer Polytechnic Institute

The Stress Rupture and Creep Properties of Heat Resistant Gas Turbine Alloys, by Nicholas J. Grant, Massachusetts Institute of Technology

Structural Variations in Gas Turbine Alloys Revealed by the Stress-Rupture Test, by Nicholas J. Grant, Massachusetts Institute of Technology

Magnesium Alloys

ROOM 20, MUNICIPAL AUDITORIUM

Some Special Metallographic Techniques for Magnesium Alloys, by P. F. George, Dow Chemical Co.

Calculation of Press Forging Pressures and Application to Magnesium Forgings, by R. L. Dietrich and G. Ansel, Dow Chemical Co.

Plastic Deformational Analyses on Pure Magnesium, by Louis A. Carapella and William E. Shaw, Mellon Institute of Industrial Research

Stainless Steel

ROOM 21, MUNICIPAL AUDITORIUM

Stability of Austenite in Stainless Steels, by C. B. Post and W. S. Eberly, Carpenter Steel Co.

The Cold Work Hardening Properties of Stainless Steel in Compression, by F. K. Bloom, G. N. Goller and P. G. Mabus, Rustless Iron & Steel Div., American Rolling Mill Co.

Quantitative Evaluation of Intergranular Corrosion of 18-8 Ti, by Freeman J. Phillips, Carnegie-Illinois Steel Corp.

Monday, Nov. 18—2:00 P. M.

Steelmaking

ROOM 20, MUNICIPAL AUDITORIUM

Ladle Deoxidation of Killed Steel With Silicon Carbide and Its Effect on Physical Properties and Hardenability, by E. A. Loria and A. P. Thompson, Mellon Institute of Industrial Research

The Physical Chemistry of Acid Refining Process, by Yap Chu-Phay, National Resources Commission of China

The Chromium-Oxygen Equilibrium in Liquid Iron, by Hsin-Min Chen, Carnegie-Illinois Steel Corp., and John Chipman, Massachusetts Institute of Technology

Nonferrous Alloys

ROOM 21, MUNICIPAL AUDITORIUM

The Precipitation Heat Treatment of Work Hardened 61S-W Aluminum Alloy, by J. J. Warga, Kaiser Fleetwings

Constitution of the System Indium-Tin, by F. N. Rhines, W. M. Urquhart and H. R. Hoge, Carnegie Institute of Technology

New Wrought Zinc Alloys Containing Small Amounts of Beryllium, by R. H. Harrington, General Electric Co.

Tuesday, Nov. 19—10:00 A. M.

Heat Treatment of Toolsteels

BALLROOM, MUNICIPAL AUDITORIUM

Bainitic Hardening of High Speed Steel, by C. K. Baer and Peter Payson, Crucible Steel Co. of America

The Tempering of High-Alloy Toolsteels, by G. A. Roberts, A. H. Grobe and C. F. Moersch, Jr., Vanadium-Alloys Steel Co.

Changes in Size and Toughness of High-Carbon High-Chromium Steels Due to Subzero Treatments, by L. E. Gippert and G. M. Butler, Jr., Allegheny Ludlum Steel Corp.

Crystal Structure

ROOM 20, MUNICIPAL AUDITORIUM

Pole Figures of the Effect of Some Cold Rolling Mill Variables on Low-Carbon Steel, by John Karl Wood, Jr., Pennsylvania State College

X-Ray Study of the Effect of High Hydrostatic Pressures on the Perfection of Crystals, by Louis Rosen, Santa Fe, N. M.

A Periodic Chart for Metallurgists, by Carl A. Zapffe, Baltimore, Md.

Iron Alloys

ROOM 21, MUNICIPAL AUDITORIUM

Formation and Transformation Studies of Iron-Carbon Powder Alloys, by J. F. Kahles, Univ. of Cincinnati

Carbon Concentration Control, by E. G. de Coriolis, O. E. Cullen and Jack Huebler, Surface Combustion Corp.

Decarburization During Annealing of Malleable Iron, by H. A. Schwartz and James Hedberg, National Malleable and Steel Castings Co.

Tuesday, Nov. 19—2:00 P. M.

Physical Properties and Testing

ROOM 20, MUNICIPAL AUDITORIUM

Precipitation in a Magnesium Sheet, by C. T. Haller, International Nickel Co., and C. S. Barrett, Institute for the Study of Metals, University of Chicago

Folding in the Cupping Operation, by W. M. Baldwin, Jr., and T. S. Howald, Chase Brass & Copper Co.

Bearing Properties of 24S-T Sheet and Shear Strength of 24S-T Rivets at Elevated Temperatures, by A. E. Flanigan, L. F. Tedson and J. E. Dorn, Univ. of Calif.

Temper Brittleness

ROOM 21, MUNICIPAL AUDITORIUM

Development of Temper Brittleness in Alloy Steels, by W. S. Pellini, American Brake Shoe Co., and B. R. Queneau, Carnegie-Illinois Steel Corp.

A Metallographic Etchant to Reveal Temper Brittleness in Steel, by J. B. Cohen, A. Hurlich and M. Jacobson, Watertown Arsenal

Electrolytic Conductivity as a Method for Studying Electronic Transitions in Elements—Application to Iron, Nickel and Cobalt, by W. R. Ham and C. H. Samans, American Optical Co.

For Lectures on Monday and Tuesday, see page 795

Technical Meetings and Lectures

All Meetings in Municipal Auditorium

Wednesday, Nov. 20 — 2:00 P. M.

Heat Resisting Alloys

ROOM 20, MUNICIPAL AUDITORIUM

Changes in Austenitic Chromium-Nickel Steels During Exposures at 1100 to 1700° F., by Peter Payson and C. H. Savage, Crucible Steel Co. of America

Cast Heat Resistant Alloys of the 16% Chromium, 35% nickel Type, by Howard S. Avery and Norman A. Matthews, American Brake Shoe Co.

The Apparent Influence of Grain Size on the High-Temperature Properties of Austenitic Steels, by C. L. Clark, Timken Roller Bearing Co., and J. W. Freeman, University of Michigan

Research and Inspection

ROOM 21, MUNICIPAL AUDITORIUM

A Study of Furnace Brazing as Applied to 12% Chromium Low-Carbon Steel, by T. H. Gray, Westinghouse Electric Corp.

Stress Cracking of Electroplated Lockwashers, by K. B. Valentine, Pontiac Motor Div., General Motors Corp.

Nondestructive Inspection of Mine Hoist Cable, by P. E. Cavanagh, Allen B. DuMont Laboratories, Inc., and R. S. Segsworth, General Engineering Co., Ltd.

Educational Lecture Courses

Monday, Nov. 18

2:00 P.M. Room B—Sleeve Bearing Metals

Fundamental Considerations Concerning the Behavior of Bearings, by R. W. Dayton, Battelle Memorial Institute

Some General Comments on Bearings, by Carl E. Swartz, Johns Hopkins University

Cast Bronze Bushings, by Leighton M. Long, Toledo, Ohio

Porous Metal Bushings, by A. J. Langhammer, Chrysler Corp., Amplex Division

3:00 P.M. Room A—Electronic Inspection

Electronic Methods for the Measurement of Stress in Metals, by Henry F. Hamburg, Chance Vought Aircraft Division

8:00 P.M. Room B—Sleeve Bearing Metals

Newer Bearing Materials, by I. C. Sleight, Menasco Mfg. Co., and Wayne Sink, P. R. Mallory and Co.

Electroplated Bearings, by Ralph A. Schaefer, Cleveland Graphite Bronze Co.

Aluminum Alloy Bearings, by H. Y. Hunsicker, Aluminum Co. of America

8:00 P.M. Room A—Physical Metallurgy of Aluminum

Constitution of Aluminum Alloys, by W. L. Fink, Aluminum Co. of America

Tuesday, Nov. 19

2:00 P.M. Room B—Sleeve Bearing Metals

Mechanical Features of Steel-Backed Bearings, by E. Crankshaw, Cleveland Graphite Bronze Co.

Moraine Durex-100 Engine Bearings, by J. A. Lignian, Moraine Products Division, General Motors Corp.

Bronze-Backed Bearings, by Bernard J. Esarey, National Bearing Division, American Brake Shoe Co.

Preparing Cast Iron Surfaces for Bonding, by J. H. Shoemaker, Kolene Corp.

3:00 P.M. Room A—Electronic Inspection

Spectrochemical Analysis of Metals and Alloys by Direct-Intensity Measurement Methods, by J. L. Saunderson, Dow Chemical Co.

Uses of the DuMont Cyclograph for Testing of Metals, by R. S. Segsworth, General Engineering Co., Ltd.

8:00 P.M. Room B—Sleeve Bearing Metals

Selection of Bearing Materials, by Arthur F. Underwood, General Motors Research Laboratories

Selection of Bearing Materials in the Electrical Industry, by D. F. Wilcock, Thomson Laboratory, General Electric Co.

Railroad Journal Bearings, by E. S. Pearce, Railway Service and Supply Corp.

8:00 P.M. Room A—Aluminum

Metallography of Aluminum Alloys, by F. Keller, Aluminum Co. of America

Wednesday, Nov. 20

2:00 P.M. Room B—Sleeve Bearing Metals

Aircraft Engine Bearings, by J. Palsulich, Wright Aeronautical Corp.

British Thought and Practice: How They Differ From American, by W. H. Tait, Glacier Metals Co., Ltd.

3:00 P.M. Room A—Electronic Inspection

Supersonic Inspection of Metals, by E. O. Dixon, Ladish Drop Forge Co.

Determination of Seams in Steels by Magnetic Analysis Equipment, by Charles M. Lichy, Jones & Laughlin Steel Corp.

8:00 P.M. Room A—Aluminum

Commercial Cast Aluminum Alloys, by W. E. Sicha, Aluminum Co. of America

8:00 P.M. Room B—Cast Iron

Structure of Cast Iron, by Alfred Boyles, U.S. Pipe & Foundry Co.

Thursday, Nov. 21

2:00 P.M. Room B—Cast Iron

Structure of Cast Iron, by Alfred Boyles, U.S. Pipe & Foundry Co.

3:00 P.M. Room A—Electronic Inspection

The Electron Microscope and Its Application to Metals, by C. S. Barrett, University of Chicago

4:00 P.M. Room B—Aluminum

Commercial Wrought Aluminum Alloys, by J. A. Nock, Jr., Aluminum Co. of America

Friday, Nov. 22

2:00 P.M. Room B—Cast Iron

Structure of Cast Iron, by Alfred Boyles, U.S. Pipe & Foundry Co.

2:00 P.M. Room A—Electronic Inspection

Electronics in Liquid Steel, by Harold T. Clark, Jones & Laughlin Steel Corp.

2:00 P.M. Room 20—Aluminum

Thermal Treatments of Aluminum Alloys, by E. H. Dix, Jr., Aluminum Co. of America

Technical Meetings

Simultaneous Morning and Afternoon Sessions in Municipal Auditorium

Thursday, Nov. 21 — 10:00 A. M.

Transformation of Austenite

BALLROOM, MUNICIPAL AUDITORIUM

The Interrupted Quench and Its Practical Aspects, by Howard E. Boyer, American Bosch Corp.

Experimental Studies of Continuous Cooling Transformations, by C. A. Liedholm, Curtiss-Wright Corp.

Isothermal Transformation of Austenite, by Axel Hultgren, K. Tekniska Hogskolan, Sweden

Copper Alloys

ROOM 20, MUNICIPAL AUDITORIUM

Influence of the Strain Rate and the Stress System on the Mechanical Properties of Copper, by D. J. McAdam, Jr., G. W. Geil and D. H. Woodard, National Bureau of Standards

Copper-Manganese Alloys—the Properties of Cold Worked and Annealed Alloys Containing 2 to 20% Manganese, by R. S. Dean, J. R. Long, T. R. Graham and D. P. Sugden, U.S. Bureau of Mines

Age Hardening Copper-Cobalt-Manganese Alloys, by Jay W. Fredrickson, University of Utah

Steelmaking

ROOM 21, MUNICIPAL AUDITORIUM

Ingot Factors in the Production of Seamless Gun Tubes, by J. W. Spretnak, Carnegie Institute of Technology, K. L. Fetters, Youngstown Sheet & Tube Co., and E. L. Layland, Westinghouse Electric Corp.

Kinetics of Solidification of Killed Steel Ingots, by J. W. Spretnak, Carnegie Institute of Technology

Theoretical Thermal Studies of Steel Ingot Solidification, by Victor Paschkis, Columbia University

Thursday, Nov. 21 — 2:00 P. M.

Hardness and Hardenability

ROOM 20, MUNICIPAL AUDITORIUM

The Measured Knoop Hardness of Hard Substances and Factors Affecting Its Determination, by Newman W. Thibault and Helen L. Nyquist, Norton Co.

Determination of Knoop Hardness Numbers Independent of Load, by L. P. Tarasov and N. W. Thibault, Norton Co.

Hardenability of Shallow Hardening Steels Determined by the PV Test, by B. F. Shepherd, Ingersoll-Rand Co.

Physical Properties

ROOM 21, MUNICIPAL AUDITORIUM

The Effect of Composition on the Fatigue Strength of Decarburized Steel, by L. R. Jackson and T. E. Pochapsky, Battelle Memorial Institute

Hardness Testing of Metals and Alloys at Elevated Temperatures, by Frederick P. Bens, Climax Molybdenum Co. of Michigan

Mechanical Properties of Cast Low-Alloy Steels, by Malcolm F. Hawkes, Carnegie Institute of Technology

Friday, Nov. 22 — 10:00 A M.

Carburizing

BALLROOM, MUNICIPAL AUDITORIUM

Carburized Cases of Hypo-Eutectoid Carbon Content, by P. C. Rosenthal and G. K. Manning, Battelle Memorial Institute

Carbide and Oxide in Surface Zones of Carburized Alloy Steels, by Axel Hultgren and Erik Hagglund, K. Tekniska Hogskolan, Sweden

Transformations in Krupp-Type Carburizing Steels, by A. R. Troiano and J. E. DeMoss, University of Notre Dame

Microstructure

ROOM 20, MUNICIPAL AUDITORIUM

The Effects of Microstructure on the Mechanical Properties of Steel, by J. H. Hollomon, L. D. Jaffe, D. E. McCarthy and M. R. Norton, Watertown Arsenal

Metallurgical and Structural Investigation of Steel Castings for Aircraft, by L. W. Smith and L. D. Morris, Cornell Aeronautical Laboratory

Factors Influencing the Pearlitic Microstructure of Annealed Hypo-Eutectoid Steel, by R. A. Grange, United States Steel Corp.

Cast Steels

ROOM 21, MUNICIPAL AUDITORIUM

The Effect of Manganese on the Properties of Cast Carbon and Carbon-Molybdenum Steels, by N. A. Ziegler, W. L. Meinhart and J. R. Goldsmith, Crane Co.

Relation of Quenching Rate and Hardenability to the Mechanical Properties of Several Heat Treated Cast Alloy Steels, by Charles R. Wilks, Howard S. Avery and Earnshaw Cook, American Brake Shoe Co.

A Laboratory Study of Quench Cracking in Cast Alloy Steels, by M. C. Udy and M. K. Barnett, Battelle Memorial Institute

Friday, Nov. 22 — 2:00 P. M.

Hydrogen Embrittlement

ROOM 21, MUNICIPAL AUDITORIUM

Practical Importance of Hydrogen in Metal-Arc Welding of Steel, by S. A. Herres, Battelle Memorial Institute

Effect of Composition, Heat Treatment, and Cold Work on the Hydrogen Embrittlement of Stainless Steel Wire During Cathodic Pickling, by Carl A. Zapffe, Baltimore, Md., and O. George Specht, Jr., Grede Foundries

Acid Composition, Concentration, Temperature and Pickling Time as Factors in the Hydrogen Embrittlement of Mild Steel and Stainless Steel Wire, by Carl A. Zapffe and M. Eleanor Haslem, Baltimore, Md.

Measurement of Embrittlement During Chromium and Cadmium Electroplating and the Nature of Recovery of Plated Articles, by Carl A. Zapffe and M. Eleanor Haslem, Baltimore, Md.

For Lectures on Thursday and Friday, see page 795

American Welding Society Program

All Meetings at Ambassador Hotel

Monday, Nov. 18—9:30 A. M.

Weldability

RENAISSANCE ROOM

Chairman—Gilbert E. Doan, Lehigh University
Vice-Chairman—Clarence E. Jackson, Union Carbide & Carbon Research Laboratories

Cold Cracking in the Heat-Affected Zone, by C. B. Voldrich, Battelle Memorial Institute

An Investigation of the Effect of Welding on the Transition Temperatures of Navy High-Tensile Low-Alloy Steels, by G. G. Luther, R. E. Metius, C. E. Hartbower and F. H. Laxar, Naval Research Laboratory

Influence of Geometrical Restraint and Temperature on the Toughness and Mode of Rupture of Structural Steel, by A. R. Anderson and A. G. Waggoner, Cramp Shipbuilding Corp.

Electrodes

VENETIAN ROOM

Chairman—J. H. Deppeler, Metal & Thermit Corp.
Vice-Chairman—J. H. Humberstone, Arcrods Corp.

The E601X Electrode Group, by Orville T. Barnett, Metal & Thermit Corp.

Some Recent Developments in the Manufacture of Fluxes for Automatic Submerged Arc Welding, by Willi M. Cohn, Consulting Engineer and Physicist

Development and Application of Lime Ferritic Electrodes, by D. L. Mathias and A. P. Bunk, Metal & Thermit Corp.

Railroad

CLUB 22

Chairman—A. G. Oehler, Associate Editor, *Railway Age*
Vice-Chairman—J. W. Sheffer, American Car & Fdry. Co.

Quantity Production of Railroad Passenger Cars by Resistance Welding, by A. M. Unger, Pullman-Standard Car Manufacturing Co.

Locomotive Boilers—Welded Construction, by James Partington, American Locomotive Co.

Welded Freight Car Construction, by R. L. Rex, Air Reduction

Monday, Nov. 18—2:00 P. M.

Research

RENAISSANCE ROOM

Chairman—G. E. Claussen, Chairman, University Research Committee
Vice-Chairman—Marvin Sedam, Alloy Rods Co.

Arc Atmospheres and Underbead Cracking, by M. W. Mallett and P. J. Rieppel, Battelle Memorial Institute

The X-Ray Diffraction Study of the Effect of Residual Compression on the Fatigue of Notched Specimens, by J. T. Norton, D. Rosenthal and S. B. Maloof, Massachusetts Institute of Technology

The Weldability of Ship Steels: Effects of Travel Speed, Preheat Temperature, and Arc Power Level on Notch Toughness, by Ernest E. Nippes and Warren F. Savage, Rensselaer Polytechnic Institute

Some Observations on the Weldability of High-Strength Wrought Aluminum Alloys, by W. R. Apblett, Naval Research Laboratory

Monday Afternoon (Continued)

Production

VENETIAN ROOM

Chairman—J. J. Chyle, A. O. Smith Corp.
Vice-Chairman—F. J. Whitney, Jr., Heintz Mfg. Co.

Automatic Gas Shielded Welding, by G. J. Gibson, Air Reduction Sales Co.

Jigs and Fixtures for Automatic Fusion Welding, by L. J. Berkeley, Penn Tool and Machine Co., and E. D. Morris, Linde Air Products Co.

Tool and Die Welding, by A. R. Butler and Frank E. Kessler, Welding Equipment & Supply Co.

Welding of Electric Apparatus, by E. F. Potter, Works Laboratory, General Electric Co.

Storage Tanks and Pressure Vessels

CLUB 22

Chairman—H. O. Hill, Bethlehem Steel Co.
Vice-Chairman—Harry Irrgang, W. K. Mitchell Co.

Field Erected Pressure Vessels, by Fred L. Plummer, Hammond Iron Works

Dry Seal Gas Holders, All-Welded, by Rudolf Kraus, Stacey Bros. Gas Construction Co.

Submerged-Melt Welding in Pressure Vessel Fabrication, by N. G. Schreiner, Linde Air Products Co.

Monday, Nov. 18—9:30 P. M.

Adams Lecture

RENAISSANCE ROOM

Adams Lecture, by Wendell F. Hess, Rensselaer Polytechnic Institute

Tuesday, Nov. 19—9:30 A. M.

Machinery

CLUB 22

Chairman—L. S. McPhee, Whiting Corp.
Vice-Chairman—A. J. Raymo, Baldwin Locomotive Works

The Metallurgical Effect of Flame Hardening Application, by O. M. Harrelson, Georgia School of Technology

The Evolution of Diesel Engine Block Weldment Designs, by James W. Owens, Fairbanks-Morse & Co.

Coordination of Engineering and Production in the Manufacture of Welded Products, by E. C. Brekelbaum, Harnischfeger Corp.

Resistance Welding

VENETIAN ROOM

Chairman—R. E. Powell, Western Electric Co.
Vice-Chairman—B. L. Wise, National Electric Welding Machines Co.

Flash Welding of Concentrated Areas Up to 24 Sq. In. in S.A.E. 1020, N.E. 9440, and N.E. 8620 Steels, by D. Bruce Johnston, McPhee and Johnston

Resistance Welding of Spring Steel to Low-Carbon Steel, by Arthur Willink, Registered Professional Engineer

Design for Resistance Welding, by I. A. Crawford, Ex-Cell-O Steel Products Co.

American Welding Society Program

All Meetings at Ambassador Hotel

Tuesday Morning (Continued)

Research

RENAISSANCE ROOM

Chairman—Charles H. Jennings, Westinghouse Electric Corp.

Vice-Chairman—George G. Luther, Naval Research Laboratory

Computation of Cooling Time in Butt Welds, by D. Rosenthal, Massachusetts Institute of Technology

Effect of Peening on Residual Welding Stresses, by Paul DeGarmo, Finn Jonassen and J. L. Meriam, University of California

Welding of High-Strength Steels With Ferritic Electrodes, by S. A. Herres and P. E. Woodward, Watertown Arsenal Laboratory

Tuesday, Nov. 19—2:00 P. M.

Research

RENAISSANCE ROOM

Chairman—John W. Gore, Bethlehem Steel Co., Baltimore Yard

Vice-Chairman—H. L. Ingram, Jr., Air Reduction

Redistribution of Residual Welding Stresses by Tensile Loading Along a Unionmelt Weld Joining Two 3-Ft.x 12-Ft.x1-In. Plates, by J. L. Meriam, E. Paul DeGarmo and Finn Jonassen, University of California

Welding Research as Applied in the South, by W. W. Austin, Jr., and E. N. Kemler, Southern Research Institute

Welding of Hardenable Steels With High-Alloy (Austenitic) Electrodes, by Miss A. M. Turkalo and Capt. S. A. Herres, Watertown Arsenal Laboratory

An Investigation of the Phenomenon of Cleavage-Type Fractures in Low-Alloy Structural Ship Steels, by H. J. Gershenow and G. G. Luther, Naval Research Laboratory

Resistance Welding

VENETIAN ROOM

Chairman—R. T. Gillette, General Electric Co.

Vice-Chairman—George N. Sieger, S-M-S Corp.

Resistance Welding With Storage Batteries, by John D. Gordon, Progressive Welder Co.

A Summary of the Spot Welding of High-Tensile Carbon and Low-Alloy Steels, by W. D. Doty and Wylie J. Childs, Rensselaer Polytechnic Institute

Selecting Spot Welding Schedules for Low-Carbon Steel, by Julius Heuschkel, Westinghouse Electric Laboratories

Shipbuilding

CLUB 22

Chairman—H. W. Pierce, New York Shipbuilding Corp.

Vice-Chairman—T. M. Jackson, Sun Shipbuilding & Dry Dock Co.

Some Problems of Welding Design and Fabrication of Steel Floating Dry Docks, by A. Amirikian, Bureau of Yards and Docks, Navy Department

Control of Welding Stresses by Welding Sequence, by Paul Ffield, Shipbuilding Division, Bethlehem Steel Co.

Discussion—Final Report of the Board to Investigate the Design and Methods of Construction of Welded Steel Merchant Vessels, by Comdr. R. D. Schmidtman, J. Lyell Wilson and Finn Jonassen, Members of the Sub-Board

Wednesday, Nov. 20—9:30 A. M.

Cutting

RENAISSANCE ROOM

Chairman—John J. Crowe, Air Reduction

Vice-Chairman—A. B. Gordon, Linde Air Products Co.

Automatic Oxy-Acetylene Operations, by S. D. Baumer, Air Reduction

Heavy Cutting Applications in Foundry and Steel Mill, by R. S. Babcock, Linde Air Products Co.

Stainless Steel Cutting, by Howard Hughey, Air Reduction

Resistance Welding

VENETIAN ROOM

Chairman—O. C. Frederick, General Electric Co.

Vice-Chairman—John Cumberland, Arcway Equipment

Additional Timing Period of New Motor-Driven Control Increases Gun Welder Speed, by H. I. Stanback, Square D Co.

Radiography and the Fatigue Strength of Spot Welds in Aluminum Alloys, by Robert C. McMaster and Horace J. Grover, Battelle Memorial Institute

Resistance Welding—A General Electric film to be shown by L. D. T. Berg, General Electric Co.

Structural

CLUB 22

Chairman—F. H. Frankland, Consulting Engineer

Vice-Chairman—W. E. Hendricks, Belmont Iron Works

H-Section Welded Trusses, by A. T. Waidelich, Austin Co.

Welded Pier Leg, Shear Leg and Trolley of a 15-Ton Ore Bridge, by Geo. F. Wolfe, Dravo Corp.

Recent Trends in Concepts of Design for Welded Steel Structures, by LaMotte Grover, Air Reduction

Wednesday, Nov. 20—2:00 P. M.

Resistance Welding

RENAISSANCE ROOM

Chairman—K. W. Ostrom, K. W. Ostrom & Co.

Vice-Chairman—E. S. Elwood, Denton and Anderson Co.

Choice of Cable and Transformer Size for Portable Spot Welder, by Myron Zucker, MacKworth G. Rees, Inc.

Three-Phase Balanced Load Resistance Welding Machines, by Mario Sciaky, Sciaky Brothers

The Flash Welding of Hard Drawn High-Carbon Steel Wire, by R. W. Bennett and R. D. Williams, Battelle Memorial Institute

Cutting

VENETIAN ROOM

Chairman—J. H. Zimmerman, Linde Air Products Co.

Vice-Chairman—John D. Bert, Philadelphia Navy Yard

Arc-Oxygen Cutting on the Surface and Under Water, by Charles Kandel, Craftsweld Equipment Corp.

Powder Cutting and Scarfing of Oxidation Resistant Materials, by D. H. Fleming, Linde Air Products Co.

Some Recent Canadian Contributions to Oxygen Cutting, and Film "No Keener Blade", by R. A. Dunn, Canadian Liquid Air Co., Ltd.

Oxygen Cutting of Steel at Elevated Temperatures, by J. F. Kiernan and J. S. Sohn, Air Reduction

American Welding Society Program

All Meetings at Ambassador Hotel

Wednesday Afternoon (Continued)

Welding Alloy Steels

CLUB 22

Chairman—R. D. Thomas, Jr., Arcos Corp.
Vice-Chairman—A. A. Holzbaur, Sun Shipbuilding Co.

Investigation of the Weldability of Copper-Bearing Steels, by N. H. Keyser and C. H. Lorig, Battelle Memorial Institute

The Control of Weld Hot Cracking in Nickel-Chromium-Iron Alloys, by T. E. Kihlgren and C. E. Lacy, International Nickel Co., Research Laboratory

Welding of High-Tensile Alloy Steels in Postwar Applications, by Howard L. Miller, Republic Steel Corp.

Navy-E.E.S. Method for Determining the Applicable Welding Procedures for Steels, by Bela Ronay, U. S. Naval Engineering Experiment Station

Wednesday, Nov. 20—8:00 P. M.

Section Activities

RENAISSANCE ROOM

Chairman—F. W. Davis, Chairman, Section Advisory Committee
Vice-Chairman—J. F. Maine, Past Chairman, Cleveland Section

Section Officers will hold their Annual Dinner in the Venetian Room at 6:30 p. m. to be followed by a special open session on Section operation involving presentation of papers and discussion by Section Representatives.

Thursday, Nov. 21—9:30 A. M.

Aircraft

VENETIAN ROOM

Chairman—G. S. Mikhalapov, Air Reduction
Vice-Chairman—P. H. Merriman, The Glenn L. Martin Co.

Design and Production Control Silver Alloy Brazed Joints in Aircraft Structures, by H. A. Smith and P. A. Koerner, Beech Aircraft Co.

Resistance Welding Test Methods Used to Maintain Quality in the Manufacture of the 140 Jet Engine, by P. G. Parks, Solar Aircraft Co.

Welding Problems in Jet Propulsion—Stainless Steel, by E. J. DeWitt and Mr. Lammers, Wallace Supplies Mfg. Co.

Hard Facing

CLUB 22

Chairman—A. V. Harris, Haynes Stellite Co.
Vice-Chairman—M. W. Brewster, Westinghouse Electric Corp.

Repairing Contractors' and Steel Mill Equipment With Manganese Application Bars, by L. A. Davis, Manganal Div., Stulz Sickles Co.

How to Select Wear Resisting Alloys for Welding, by Joseph A. Cunningham, J. A. Cunningham Equipment, Inc.

Microstructure of Hard Facing Alloys, by H. W. Sharp, Stoody Co.

Composite Construction by Building up Surfaces With Submerged-Melt Welding, by J. E. Taylerson, Linde Air Products Co.

Thursday Morning (Continued)

Pressure Welding

RENAISSANCE ROOM

Chairman—A. B. Kinzel, Union Carbide & Carbon Research Laboratories
Vice-Chairman—A. T. Light, York Corp.

Open Butt Oxy-Acetylene Compression Welding, by H. H. Chiswik, Air Reduction

Pressure Welding of Low-Alloy Steels and Some Nonferrous Alloys, by K. H. Koopman, Union Carbide and Carbon Research Laboratories, Inc.

Welding of Stainless Steel Rings, by C. J. Burch, Linde Air Products Co., A. L. Rustay, Stephen Jablonski, and Alan Crowell, Wyman-Gordon Co.

Pressure Gas Welding of Alloy Steel Tubing, by Z. L. Zambrow and R. D. Williams, Battelle Memorial Institute

Friday, Nov. 22—9:30 A. M.

High Alloys

RENAISSANCE ROOM

Chairman—R. D. Thomas, Sr., Arcos Corp.
Vice-Chairman—E. R. McClung, Lukenweld, Inc.

An Attempt to Select a Suitable Specimen for the Study of Corrosion Cracking in 18-8 Steel, by D. S. McKinney, Carnegie Institute of Technology

Welding and Other Fabrication Methods for Hastelloy Alloys, by C. G. Chisholm, Haynes Stellite Co.

Effect of Alloying Elements on the Tensile Properties of 25-20 Weld Metal, by Hallock C. Campbell and R. D. Thomas, Jr., Arcos Corp.

Miscellaneous

VENETIAN ROOM

Chairman—H. B. Seydel, Air Reduction
Vice-Chairman—G. R. Johnson, Lincoln Electric Co.

The Arc Welding of Cast Iron With Nickel Electrodes, by T. E. Kihlgren and L. C. Minard, International Nickel Co., Research Laboratory

The Welding of High-Temperature, High-Pressure Steel Valves, by Vincent Malcolm, Chapman Valve Co.

Static and Fatigue Tests of Arc Welded Aluminum Alloy 61S-T Plate, by E. C. Hartmann, Marshall Holt and A. N. Zamboky, Aluminum Research Laboratories

Miscellaneous

CLUB 22

Chairman—G. V. Slottman, Air Reduction
Vice-Chairman—L. D. T. Berg, General Electric Co.

Submerged-Melt Welding of Corrosion Resisting Metals, by H. J. Roberts, Linde Air Products Co., and R. J. Anderson, Dominion Oxygen Co., Ltd.

Production Applications of Inert-Gas Shielded Arc Welding, by H. T. Herbst, Linde Air Products Co.

A New Semiautomatic Arc Welding Process, by J. M. Tyrner, Air Reduction

American Institute of Mining and Metallurgical Engineers

All Meetings Held at Hotel Claridge

Monday, Nov. 18 — 10:00 A. M.

General Technical Session

IRON AND STEEL DIVISION

German Iron Ores Yield Vanadium, by R. P. Fischer

Controlled Atmospheres From City Gas for the Heat Treatment of Steels, by Ivor Jenkins

Production of Low-Sulphur Sponge Iron, by R. C. Buehl, E. P. Shoub and J. P. Riott

Aluminum Alloys

INSTITUTE OF METALS DIVISION

Precipitation in Age Hardened Aluminum Alloys, by A. H. Geisler and F. Keller

Stress-Rupture and Creep Tests on Aluminum Alloy Sheet at Elevated Temperatures, by A. E. Flanagan, L. F. Tedsen and J. E. Dorn

Monday, Nov. 18 — 2:00 P. M.

Joint Technical Session on Magnesium Alloys and Oxide Films

IRON AND STEEL AND INSTITUTE OF METALS DIVISIONS

Hydrogen in Magnesium Alloys, by R. S. Busk and E. G. Bobalek

Some Effects of Zirconium on the Extrusion Properties of Magnesium-Base Alloys Containing Zinc, by J. P. Doan and G. Ansel

An Electron Diffraction Study of Oxide Films Formed on Fe, Co, Ni, Cr and Cu at High Temperatures, by E. A. Gulbransen and J. W. Hickman

An Electron Diffraction Study of Oxide Films Formed on Alloys of Fe, Co, Ni and Cr at High Temperatures, by J. W. Hickman and E. A. Gulbransen

Metallography

IRON AND STEEL DIVISION

Hot Deformation Structures, Banding and Red Shortness Cracks in Steel, by A. Hultgren and B. Herrlander

Transformation of Austenite in an Aluminum-Chromium-Molybdenum Steel, by R. A. Grange, W. S. Holt and E. T. Tkac

Effect of Alloys in Steel on Resistance to Tempering, by Walter Crafts and J. L. Lamont

Calculation of Tensile Strength and Yield Point From the Chemical Composition and Cooling Rate, by I. R. Kramer, P. D. Gorsuch and D. L. Newhouse

Boron in Certain Alloy Steels, by M. C. Udy and P. C. Rosenthal

Tuesday Morning, Nov. 19

9:00 A.M.—Joint Symposium on Effects of Multiaxial Stresses on Metals

IRON AND STEEL AND INSTITUTE OF METALS DIVISIONS

Mechanical Equation of State, by J. H. Hollomon

A Statistical Theory of Fracture, by J. C. Fisher and J. H. Hollomon

A Thermodynamic Theory of the Fracture of Metals, by E. Saibel

10:45 A.M.—Annual Lecture

INSTITUTE OF METALS DIVISION

Electrons, Atoms, Metals and Alloys, by William Hume-Rothery, Oxford University, England

Tuesday, Nov. 19 — 2:00 P. M.

Joint Symposium on Effects of Multiaxial Stresses on Metals

IRON AND STEEL AND INSTITUTE OF METALS DIVISIONS

Work Hardening and Rupture in Metals, by L. R. Jackson

Comparison of Various Structural Alloy Steels by Means of the Static Notched-Bar Tensile Test, by G. Sachs, L. F. Ebert and W. F. Brown, Jr.

Plastic Flow of Aluminum Alloy Sheet Under Combined Loads, by W. T. Lankford, J. R. Low and M. Gensamer

Problems in Unstable Flow Under Biaxial Stresses, by W. T. Lankford and E. A. Saibel

General Technical Session

INSTITUTE OF METALS DIVISION

Some Factors Affecting the Particle Size of Tungsten, by Bernard Kopelman

Spot Welding of Titanium, by R. S. Dean, J. R. Long, E. T. Hayes and D. C. Root

The Melting of Molybdenum in the Vacuum Arc, by R. M. Parke and J. L. Ham

Solubility of Hydrogen in Electrolytic Manganese and Transition Points in Electrolytic Manganese, by E. V. Potter and H. C. Lukens

Tuesday, Nov. 19 — 6:30 P. M.

Annual Fall Dinner

IRON AND STEEL AND INSTITUTE OF METALS DIVISIONS

A.I.M.E Technical Program (Continued)

Wednesday, Nov. 20—2:00 P. M.

Copper Alloys and Metallography

INSTITUTE OF METALS DIVISION

Twin Relationships in Annealed Copper Strip, by P. Coheur and C. S. Barrett

Twinning in Polycrystalline Magnesium, by C. S. Barrett and C. T. Haller

Zinc Diffusion in Alpha Brass, by A. Smigelskas and E. O. Kirkendall

The Alpha Solid Solution Area of the Copper-Manganese-Aluminum System, by R. S. Dean, J. R. Long, T. R. Graham, A. H. Roberson and C. E. Armantrout

Wednesday, Nov. 20—2:30 P. M.

Physical Chemistry of Blast Furnace and Openhearth

IRON AND STEEL DIVISION

An Electrochemical Study of the Properties of Molten Slags of the Systems CaO-SiO_2 and CaO-Al_2O_3-SiO_2, by L. C. Chang and Gerhard Derge

Oxygen in Liquid Openhearth Steel. II—Oxygen Content During the Refining Period, by T. E. Brower and B. M. Larsen

Oxygen in Liquid Openhearth Steel. Effect of Special Additions, Stirring Methods and Tapping, by T. E. Brower and B. M. Larsen

American Industrial Radium & X-Ray Society

All Meetings Held in Main Ballroom, Seaside Hotel

ADMISSION TO SESSIONS IS BY MEMBERSHIP CARD ONLY

Wednesday, Nov. 20

9:30 A. M.—Quantitative Measurement of Penetrating Radiation

Technical Chairman—Lloyd W. Pote, chairman, Boston Section

Quantitative Measurements by Controlled Process Film of Two Million Volt X-Radiation, by Donald T. O'Connor, Naval Ordnance Laboratory

Quantitative Relations Between the Photographic Response of Typical X-Ray Films and the Quality of Radiation, by Victor Hicks and H. W. Hoerlin, Ansco

Sliding Scales to Increase the Usefulness of Radiographic Exposure Charts, by Herman E. Seemann and George M. Corney, Eastman Kodak Co.

Applications of G-M Counters to Measurement of X-Ray and Gamma-Ray Intensities, by Herbert Friedman, Naval Research Laboratory

2:00 P. M.—Commercial and Research Applications of Radiography

Technical Chairman—Paul F. Duttenhofer, chairman, Philadelphia Section

Design, Manufacture and Inspection of Welded Fabrications, by Gerald H. Campbell, A. O. Smith Corp.

X-Ray Inspection of Rocket Propellants, by Joseph E. Watkins, General Electric X-Ray Corp.

Radiography of Heavy Radioactive Materials, by Gerold H. Tenney, Los Alamos Project

Gamma-Ray Radiography in a Small Steel Foundry, by Robert A. Willey, Commercial Steel Casting Co.

Thursday, Nov. 21

9:30 A. M.—Radiation Methods for Fine Structure Analysis

Technical Chairman—R. V. Lange, chairman, New York Section

A Study of the Microstructure of Some Nonferrous Alloys by Means of Microradiography, by Louis Conant, Lithaloys Corp.

X-Ray and Optical Micrography as Essentials to Correlation of Radiographic Appearance With the Serviceability of Metal Parts, by Leslie W. Ball, Naval Ordnance Laboratory

Microscopy and Analysis With Electrons, by James Hillier, Radio Corp. of America

Short Source-Object-Distance Exposure Techniques in Spot Weld Radiography, by Robert C. McMaster, Battelle Memorial Institute

2:00 P. M.—Annual Meeting and Mehl Lecture

Election of Officers

The Retiring President's Address, by Kent R. Van Horn

Photographic Aspects of Industrial Radiography, by Herman E. Seemann, Eastman Kodak Co. (Mehl Lecture)

Friday, Nov. 22

9:30 A. M.—Technique and Diagnosis Standardization

Technical Chairman—Norman Deuel, chairman, Baltimore Section

Logarithmic Step-Tablet for X-Rays, by George M. Corney, Eastman Kodak Co.

Further Studies of High-Voltage Radiography, by E. Dale Trout, General Electric X-Ray Corp.

Radiographic Specifications, Their Nature, Purpose and Current Revisions, by J. Jerome Pierce, Naval Ordnance Laboratory

2:00 P. M.—Nondestructive or Allied Test Methods

Technical Chairman—Lt. Comdr. W. W. Chambers, Naval Medical Center

Spectrographic Analysis of Cartridge Brass, by M. M. White, Willys-Overland Motors, Inc.

Proof Loading—An Essential Nondestructive Test, by John C. New, Naval Ordnance Laboratory

Analysis of Drillings and Chips by Sintering Pellets of the Material, by M. M. White, Willys-Overland Motors, Inc.

Testing Metals for Internal Discontinuities With Supersonic Echoes, by J. W. Dice, Sperry Products, Inc.

Conversion Tables for Lengths

Based on value 1 m. = 39.37 in.

From "Ready Reference Tables", by Carl Hering

In. = / Mm. = / Feet = / M. = / Yd. = / Miles = / Km. =	millimeters	inches	meters	feet	meters	yards	kilometers	miles
1	25.400 1	0.039 370	0.304 801	3.280 83	0.914 402	1.093 61	1.609 35	0.621 37
2	50.800 1	0.078 740	0.609 601	6.561 67	1.828 80	2.187 22	3.218 69	1.242 74
3	76.200 2	0.118 110	0.914 402	9.842 50	2.743 21	3.280 83	4.828 04	1.864 11
4	101.600	0.157 480	1.219 20	13.123 3	3.657 61	4.374 44	6.437 39	2.485 48
5	127.000	0.196 850	1.524 00	16.404 2	4.572 01	5.468 06	8.046 74	3.106 85
6	152.400	0.236 220	1.828 80	19.685 0	5.486 41	6.561 67	9.656 08	3.728 22
7	177.800	0.275 590	2.133 60	22.965 8	6.400 81	7.655 28	11.265 4	4.349 59
8	203.200	0.314 960	2.438 40	26.246 7	7.315 21	8.748 89	12.874 8	4.970 96
9	228.600	0.354 330	2.743 21	29.527 5	8.229 62	9.842 50	14.484 1	5.592 33
10	254.001	0.393 700	3.048 01	32.808 3	9.144 02	10.936 1	16.093 5	6.213 70
11	279.401	0.433 070	3.352.81	36.089 2	10.058 4	12.029 7	17.702 8	6.835 07
12	304.801	0.472 440	3.657 61	39.370 0	10.972 8	13.123 3	19.312 2	7.456 44
13	330.201	0.511 810	3.962 41	42.650 8	11.887 2	14.216 9	20.921 5	8.077 81
14	355.601	0.551 180	4.267 21	45.931 7	12.801 6	15.310 6	22.530 9	8.699 18
15	381.001	0.590 550	4.572 01	49.212 5	13.716 0	16.404 2	24.140 2	9.320 55
16	406.401	0.629 920	4.876 81	52.493 3	14.630 4	17.497 8	25.749 6	9.941 92
17	431.801	0.669 290	5.181 61	55.774 2	15.544 8	18.591 4	27.358 9	10.563 3
18	457.201	0.708 660	5.486 41	59.055 0	16.459 2	19.685 0	28.968 2	11.184 7
19	482.601	0.748 030	5.791 21	62.335 8	17.373 6	20.778 6	30.577 6	11.806 0
20	508.001	0.787 400	6.096 01	65.616 7	18.288 0	21.872 2	32.186 9	12.427 4
21	533.401	0.826 770	6.400 81	68.897 5	19.202 4	22.965 8	33.796 3	13.048 8
22	558.801	0.866 140	6.705 61	72.178 3	20.116 8	24.059 4	35.405 6	13.670 1
23	584.201	0.905 510	7.010 41	75.459 2	21.031 2	25.153 1	37.015 0	14.291 5
24	609.601	0.944 880	7.315 21	78.740 0	21.945 6	26.246 7	38.624 3	14.912 9
25	635.001	0.984 250	7.620 02	82.020 8	22.860 0	27.340 3	40.233 7	15.534 2
26	660.401	1.023 62	7.924 82	85.301 7	23.774 4	28.433 9	41.843 0	16.155 6
27	685.801	1.062 99	8.229 62	88.582 5	24.688 9	29.527 5	43.452 4	16.777 0
28	711.201	1.102 36	8.534 42	91.863 3	25.603 3	30.621 1	45.061 7	17.398 4
29	736.601	1.141 73	8.839 22	95.144 2	26.517 7	31.714 7	46.671 1	18.019 7
30	762.002	1.181 10	9.144 02	98.425 0	27.432 1	32.808 3	48.280 4	18.641 1
31	787.402	1.220 47	9.448 82	101.706	28.346 5	33.901 9	49.889 8	19.262 5
32	812.802	1.259 84	9.753 62	104.987	29.260 9	34.995 6	51.499 1	19.883 8
33	838.202	1.299 21	10.058 4	108.268	30.175 3	36.089 2	53.108 5	20.505 2
34	863.602	1.338 58	10.363 2	111.548	31.089 7	37.182 8	54.717 8	21.126 6
35	889.002	1.377 95	10.668 0	114.829	32.004 1	38.276 4	56.327 2	21.747 9
36	914.402	1.417 32	10.972 8	118.110	32.918 5	39.370 0	57.936 5	22.369 3
37	939.802	1.456 69	11.277 6	121.391	33.832 9	40.463 6	59.545 8	22.990 7
38	965.202	1.496 06	11.582 4	124.672	34.747 3	41.557 2	61.155 2	23.612 1
39	990.602	1.535 43	11.887 2	127.953	35.661 7	42.650 8	62.764 5	24.233 4
40	1 016.00	1.574 80	12.192 0	131.233	36.576 1	43.744 4	64.373 9	24.854 8
41	1 041.40	1.614 17	12.496 8	134.514	37.490 5	44.838 1	65.983 2	25.476 2
42	1 066.80	1.653 54	12.801 6	137.795	38.404 9	45.931 7	67.592 6	26.097 5
43	1 092.20	1.692 91	13.106 4	141.076	39.319 3	47.025 3	69.201 9	26.718 9
44	1 117.60	1.732 28	13.411 2	144.357	40.233 7	48.118 9	70.811 3	27.340 3
45	1 143.00	1.771 65	13.716 0	147.638	41.148 1	49.212 5	72.420 6	27.961 6
46	1 168.40	1.811 02	14.020 8	150.918	42.062 5	50.306 1	74.030 0	28.583.0
47	1 193.80	1.850 39	14.325 6	154.199	42.976 9	51.399 7	75.639 3	29.204 4
48	1 219.20	1.889 76	14.630 4	157.480	43.891 3	52.493 3	77.248 7	29.825 8
49	1 244.60	1.929 13	14.935 2	160.761	44.805 7	53.586 9	78.858 0	30.447 1
50	1 270.00	1.968 50	15.240 0	164.042	45.720 1	54.680 6	80.467 4	31.068 5

In. = / Mm. = / Feet = / M. = / Yd. = / Miles = / Km. =	millimeters	inches	meters	feet	meters	yards	kilometers	miles
51	1 295.40	2.007 87	15.544 8	167.323	46.634 5	55.774 2	82.076 7	31.689 9
52	1 320.80	2.047 24	15.849 6	170.603	47.548 9	56.867 8	83.686 1	32.311 2
53	1 346.20	2.086 61	16.154 4	173.884	48.463 3	57.961 4	85.295 4	32.932 6
54	1 371.60	2.125 98	16.459 2	177.165	49.377 7	59.055 0	86.904 7	33.554 0
55	1 397.00	2.165 35	16.764 0	180.446	50.292 1	60.148 6	88.514 1	34.175 3
56	1 422.40	2.204 72	17.068 8	183.727	51.206 5	61.242 2	90.123 4	34.796 7
57	1 447.80	2.244 09	17.373 6	187.008	52.120 9	62.335 8	91.732 8	35.418 1
58	1 473.20	2.283 46	17.678 4	190.288	53.035 3	63.429 4	93.342 1	36.039 5
59	1 498.60	2.322 83	17.983 2	193.569	53.949 7	64.523 1	94.951 5	36.660 8
60	1 524.00	2.362 20	18.288 0	196.850	54.864 1	65.616 7	96.560 8	37.282 2
61	1 549.40	2.401 57	18.592 8	200.131	55.778 5	66.710 3	98.170 2	37.903 6
62	1 574.80	2.440 94	18.897 6	203.412	56.692 9	67.803 9	99.779 5	38.524 9
63	1 600.20	2.480 31	19.202 4	206.693	57.607 3	68.897 5	101.389	39.146 3
64	1 625.60	2.519 68	19.507 2	209.973	58.521 7	69.991 1	102.998	39.767 7
65	1 651.00	2.559 05	19.812 0	213.254	59.436 1	71.084 7	104.608	40.389 0
66	1 676.40	2.598 42	20.116 8	216.535	60.350 5	72.178 3	106.217	41.010 4
67	1 701.80	2.637 79	20.421 6	219.816	61.264 9	73.271 9	107.826	41.631 8
68	1 727.20	2.677 16	20.726 4	223.097	62.179 3	74.365 6	109.436	42.253 2
69	1 752.60	2.716 53	21.031 2	226.378	63.093 7	75.459 2	111.045	42.874 5
70	1 778.00	2.755 90	21.336 0	229.658	64.008 1	76.552 8	112.654	43.495 9
71	1 803.40	2.795 27	21.640 8	232.939	64.922 5	77.646 4	114.264	44.117 3
72	1 828.80	2.834 64	21.945 6	236.220	65.836 9	78.740 0	115.873	44.738 6
73	1 854.20	2.874 01	22.250 4	239.501	66.751 3	79.833 6	117.482	45.360 0
74	1 879.60	2.913 38	22.555 2	242.782	67.665 7	80.927 2	119.092	45.981 4
75	1 905.00	2.952 75	22.860 0	246.063	68.580 1	82.020 8	120.701	46.602 7
76	1 930.40	2.992 12	23.164 8	249.343	69.494 5	83.114 4	122.310	47.224 1
77	1 955.80	3.031 49	23.469 6	252.624	70.408 9	84.208 1	123.920	47.845 5
78	1 981.20	3.070 86	23.774 4	255.905	71.323 3	85.301 7	125.529	48.466 9
79	2 006.60	3.110 23	24.079 2	259.186	72.237 7	86.395 3	127.138	49.088 2
80	2 032.00	3.149 60	24.384 0	262.467	73.152 1	87.488 9	128.748	49.709 6
81	2 057.40	3.188 97	24.688 8	265.748	74.066 5	88.582 5	130.357	50.331 0
82	2 082.80	3.228 34	24.993 6	269.028	74.981 0	89.676 1	131.966	50.952 3
83	2 108.20	3.267 71	25.298 4	272.309	75.895 4	90.769 7	133.576	51.573 7
84	2 133.60	3.307 08	25.603 3	275.590	76.809 8	91.863 3	135.185	52.195 1
85	2 159.00	3.346 45	25.908 1	278.871	77.724 2	92.956 9	136.795	52.816 4
86	2 184.40	3.385 82	26.212 9	282.152	78.638 6	94.050 6	138.404	53.437 8
87	2 209.80	3.425 19	26.517 7	285.433	79.553 0	95.144 2	140.013	54.059 2
88	2 235.20	3.464 56	26.822 5	288.713	80.467 4	96.237 8	141.623	54.680 6
89	2 260.60	3.503 93	27.127 3	291.994	81.381 8	97.331 4	143.232	55.301 9
90	2 286.00	3.543 30	27.432 1	295.275	82.296 2	98.425 0	144.841	55.923 3
91	2 311.40	3.582 67	27.736 9	298.556	83.210 6	99.518 6	146.451	56.544 7
92	2 336.80	3.622 04	28 041 7	301.837	84.125 0	100.612	148.060	57.160 0
93	2 362.20	3.661 41	28.346 5	305.118	85.039 4	101.706	149.669	57.787 4
94	2 387.60	3.700 78	28.651 3	308.398	85.953 8	102.799	151.279	58.408 8
95	2 413.00	3.740 15	28.956 1	311.679	86.868 2	103.893	152.888	59.030 1
96	2 438.40	3.779 52	29.260 9	314.960	87.782 6	104.987	154.497	59.651 5
97	2 463.80	3.818 89	29.565 7	318.241	88.697 0	106.080	156.107	60.272 9
98	2 489.20	3.858 26	29.870 5	321.522	89.611 4	107.174	157.716	60.894 3
99	2 514.60	3.897 63	30.175 3	324 803	90.525 8	108.268	159.325	61.515 6
100	2 540.01	3.937 00	30.480 1	328.083	91.440 2	109.361	160.935	62.137 0

Temperature Conversions

49	1 244.60	1.929 13	14.935 2	160.761	44.805 7	53.586 9	78.858 0	30.447 1	99	2 514.60	3.897 63	30.175 3	324.895	91.440 2	109.361	160.935	62.137 0
50	1 270.00	1.968 50	15.240 0	164.042	45.720 1	54.680 6	80.467 4	31.068 5	100	2 540.01	3.937 00	30.480 1	328.083				

Temperature Conversions

Albert Sauveur type of table. Look up reading in middle column; if in degrees Centigrade, read Fahrenheit equivalent in right-hand column; if in degrees Fahrenheit, read Centigrade equivalent in left-hand column. Values as printed in "Bethlehem Alloy Steels".

−459.4 to 0			0 to 100						100 to 1000						1000 to 2000						2000 to 3000					
C		F	C		F	C		F	C		F	C		F	C		F	C		F	C		F	C		F
−273	*−459.4*		−17.8	*0*	32	10.0	*50*	122.0	38	*100*	212	260	*500*	932	538	*1000*	1832	816	*1500*	2732	1093	*2000*	3632	1371	*2500*	4532
−268	*−450*		−17.2	*1*	33.8	10.6	*51*	123.8	43	*110*	230	266	*510*	950	543	*1010*	1850	821	*1510*	2750	1099	*2010*	3650	1377	*2510*	4550
−262	*−440*		−16.7	*2*	35.6	11.1	*52*	125.6	49	*120*	248	271	*520*	968	549	*1020*	1868	827	*1520*	2768	1104	*2020*	3668	1382	*2520*	4568
−257	*−430*		−16.1	*3*	37.4	11.7	*53*	127.4	54	*130*	266	277	*530*	986	554	*1030*	1886	832	*1530*	2786	1110	*2030*	3686	1388	*2530*	4586
−251	*−420*		−15.6	*4*	39.2	12.2	*54*	129.2	60	*140*	284	282	*540*	1004	560	*1040*	1904	838	*1540*	2804	1116	*2040*	3704	1393	*2540*	4604
−246	*−410*		−15.0	*5*	41.0	12.8	*55*	131.0	66	*150*	302	288	*550*	1022	566	*1050*	1922	843	*1550*	2822	1121	*2050*	3722	1399	*2550*	4622
−240	*−400*		−14.4	*6*	42.8	13.3	*56*	132.8	71	*160*	320	293	*560*	1040	571	*1060*	1940	849	*1560*	2840	1127	*2060*	3740	1404	*2560*	4640
−234	*−390*		−13.9	*7*	44.6	13.9	*57*	134.6	77	*170*	338	299	*570*	1058	577	*1070*	1958	854	*1570*	2858	1132	*2070*	3758	1410	*2570*	4658
−229	*−380*		−13.3	*8*	46.4	14.4	*58*	136.4	82	*180*	356	304	*580*	1076	582	*1080*	1976	860	*1580*	2876	1138	*2080*	3776	1416	*2580*	4676
−223	*−370*		−12.8	*9*	48.2	15.0	*59*	138.2	88	*190*	374	310	*590*	1094	588	*1090*	1994	866	*1590*	2894	1143	*2090*	3794	1421	*2590*	4694
−218	*−360*		−12.2	*10*	50.0	15.6	*60*	140.0	93	*200*	392	316	*600*	1112	593	*1100*	2012	871	*1600*	2912	1149	*2100*	3812	1427	*2600*	4712
−212	*−350*		−11.7	*11*	51.8	16.1	*61*	141.8	99	*210*	410	321	*610*	1130	599	*1110*	2030	877	*1610*	2930	1154	*2110*	3830	1432	*2610*	4730
−207	*−340*		−11.1	*12*	53.6	16.7	*62*	143.6	100	*212*	413.6	327	*620*	1148	604	*1120*	2048	882	*1620*	2948	1160	*2120*	3848	1438	*2620*	4748
-201	*−330*		−10.6	*13*	55.4	17.2	*63*	145.4	104	*220*	428	332	*630*	1166	610	*1130*	2066	888	*1630*	2966	1166	*2130*	3866	1443	*2630*	4766
−196	*−320*		−10.0	*14*	57.2	17.8	*64*	147.2	110	*230*	446	338	*640*	1184	616	*1140*	2084	893	*1640*	2984	1171	*2140*	3884	1449	*2640*	4784
−190	*−310*		− 9.4	*15*	59.0	18.3	*65*	149.0	116	*240*	464	343	*650*	1202	621	*1150*	2102	899	*1650*	3002	1177	*2150*	3902	1454	*2650*	4802
−184	*−300*		− 8.9	*16*	60.8	18.9	*66*	150.8	121	*250*	482	349	*660*	1220	627	*1160*	2120	904	*1660*	3020	1182	*2160*	3920	1460	*2660*	4820
−179	*−290*		− 8.3	*17*	62.6	19.4	*67*	152.6	127	*260*	500	354	*670*	1238	632	*1170*	2138	910	*1670*	3038	1188	*2170*	3938	1466	*2670*	4838
−173	*−280*		− 7.8	*18*	64.4	20.0	*68*	154.4	132	*270*	518	360	*680*	1256	638	*1180*	2156	916	*1680*	3056	1193	*2180*	3956	1471	*2680*	4856
−169	*−273*	−459.4	− 7.2	*19*	66.2	20.6	*69*	156.2	138	*280*	536	366	*690*	1274	643	*1190*	2174	921	*1690*	3074	1199	*2190*	3974	1477	*2690*	4874
−168	*−270*	−454	− 6.7	*20*	68.0	21.1	*70*	158.0	143	*290*	554	371	*700*	1292	649	*1200*	2192	927	*1700*	3092	1204	*2200*	3992	1482	*2700*	4892
−162	*−260*	−436	− 6.1	*21*	69.8	21.7	*71*	159.8	149	*300*	572	377	*710*	1310	654	*1210*	2210	932	*1710*	3110	1210	*2210*	4010	1488	*2710*	4910
−157	*−250*	−418	− 5.6	*22*	71.6	22.2	*72*	161.6	154	*310*	590	382	*720*	1328	660	*1220*	2228	938	*1720*	3128	1216	*2220*	4028	1493	*2720*	4928
−151	*−240*	−400	− 5.0	*23*	73.4	22.8	*73*	163.4	160	*320*	608	388	*730*	1346	666	*1230*	2246	943	*1730*	3146	1221	*2230*	4046	1499	*2730*	4946
−146	*−230*	−382	− 4.4	*24*	75.2	23.3	*74*	165.2	166	*330*	626	393	*740*	1364	671	*1240*	2264	949	*1740*	3164	1227	*2240*	4064	1504	*2740*	4964
−140	*−220*	−364	− 3.9	*25*	77.0	23.9	*75*	167.0	171	*340*	644	399	*750*	1382	677	*1250*	2282	954	*1750*	3182	1232	*2250*	4082	1510	*2750*	4982
−134	*−210*	−346	− 3.3	*26*	78.8	24.4	*76*	168.8	177	*350*	662	404	*760*	1400	682	*1260*	2300	960	*1760*	3200	1238	*2260*	4100	1516	*2760*	5000
−129	*−200*	−328	− 2.8	*27*	80.6	25.0	*77*	170.6	182	*360*	680	410	*770*	1418	688	*1270*	2318	966	*1770*	3218	1243	*2270*	4118	1521	*2770*	5018
−123	*−190*	−310	− 2.2	*28*	82.4	25.6	*78*	172.4	188	*370*	698	416	*780*	1436	693	*1280*	2336	971	*1780*	3236	1249	*2280*	4136	1527	*2780*	5036
−118	*−180*	−292	− 1.7	*29*	84.2	26.1	*79*	174.2	193	*380*	716	421	*790*	1454	699	*1290*	2354	977	*1790*	3254	1254	*2290*	4154	1532	*2790*	5054
−112	*−170*	−274	− 1.1	*30*	86.0	26.7	*80*	176.0	199	*390*	734	427	*800*	1472	704	*1300*	2372	982	*1800*	3272	1260	*2300*	4172	1538	*2800*	5072
−107	*−160*	−256	− 0.6	*31*	87.8	27.2	*81*	177.8	204	*400*	752	432	*810*	1490	710	*1310*	2390	988	*1810*	3290	1266	*2310*	4190	1543	*2810*	5090
−101	*−150*	−238	0.0	*32*	89.6	27.8	*82*	179.6	210	*410*	770	438	*820*	1508	716	*1320*	2408	993	*1820*	3308	1271	*2320*	4208	1549	*2820*	5108
− 96	*−140*	−220	0.6	*33*	91.4	28.3	*83*	181.4	216	*420*	788	443	*830*	1526	721	*1330*	2426	999	*1830*	3326	1277	*2330*	4226	1554	*2830*	5126
− 90	*−130*	−202	1.1	*34*	93.2	28.9	*84*	183.2	221	*430*	806	449	*840*	1544	727	*1340*	2444	1004	*1840*	3344	1282	*2340*	4244	1560	*2840*	5144
− 84	*−120*	−184	1.7	*35*	95.0	29.4	*85*	185.0	227	*440*	824	454	*850*	1562	732	*1350*	2462	1010	*1850*	3362	1288	*2350*	4262	1566	*2850*	5162
− 79	*−110*	−166	2.2	*36*	96.8	30.0	*86*	186.8	232	*450*	842	460	*860*	1580	738	*1360*	2480	1016	*1860*	3380	1293	*2360*	4280	1571	*2860*	5180
− 73	*−100*	−148	2.8	*37*	98.6	30.6	*87*	188.6	238	*460*	860	466	*870*	1598	743	*1370*	2498	1021	*1870*	3398	1299	*2370*	4298	1577	*2870*	5198
− 68	*− 90*	−130	3.3	*38*	100.4	31.1	*88*	190.4	243	*470*	878	471	*880*	1616	749	*1380*	2516	1027	*1880*	3416	1304	*2380*	4316	1582	*2880*	5216
− 62	*− 80*	−112	3.9	*39*	102.2	31.7	*89*	192.2	249	*480*	896	477	*890*	1634	754	*1390*	2534	1032	*1890*	3434	1310	*2390*	4334	1588	*2890*	5234
− 57	*− 70*	− 94	4.4	*40*	104.0	32.2	*90*	194.0	254	*490*	914	482	*900*	1652	760	*1400*	2552	1038	*1900*	3452	1316	*2400*	4352	1593	*2900*	5252
− 51	*− 60*	− 76	5.0	*41*	105.8	32.8	*91*	195.8				488	*910*	1670	766	*1410*	2570	1043	*1910*	3470	1321	*2410*	4370	1599	*2910*	5270
− 46	*− 50*	− 58	5.6	*42*	107.6	33.3	*92*	197.6				493	*920*	1688	771	*1420*	2588	1049	*1920*	3488	1327	*2420*	4388	1604	*2920*	5288
− 40	*− 40*	− 40	6.1	*43*	109.4	33.9	*93*	199.4				499	*930*	1706	777	*1430*	2606	1054	*1930*	3506	1332	*2430*	4406	1610	*2930*	5306
− 34	*− 30*	− 22	6.7	*44*	111.2	34.4	*94*	201.2				504	*940*	1724	782	*1440*	2624	1060	*1940*	3524	1338	*2440*	4424	1616	*2940*	5324
− 29	*− 20*	− 4	7.2	*45*	113.0	35.0	*95*	203.0				510	*950*	1742	788	*1450*	2642	1066	*1950*	3542	1343	*2450*	4442	1621	*2950*	5342
− 23	*− 10*	14	7.8	*46*	114.8	35.6	*96*	204.8				516	*960*	1760	793	*1460*	2660	1071	*1960*	3560	1349	*2460*	4460	1627	*2960*	5360
− 17.8	*0*	32	8.3	*47*	116.6	36.1	*97*	206.6				521	*970*	1778	799	*1470*	2678	1077	*1970*	3578	1354	*2470*	4478	1632	*2970*	5378
			8.9	*48*	118.4	36.7	*98*	208.4				527	*980*	1796	804	*1480*	2696	1082	*1980*	3596	1360	*2480*	4496	1638	*2980*	5396
			9.4	*49*	120.2	37.2	*99*	210.2				532	*990*	1814	810	*1490*	2714	1088	*1990*	3614	1366	*2490*	4514	1643	*2990*	5414
						37.8	*100*	212.0				538	*1000*	1832				1093	*2000*	3632				1649	*3000*	5432

Personal Mention

ROBERT W. MASON, Jr. ⊜, formerly associated with the Lithium Co., Newark, N. J., has joined the development and research division of International Nickel Co., Inc.

GEORGE W. KURACHEK ⊜, formerly foundry metallurgist with the Wright Aeronautical Corp., is now connected with the Castalloy Co., Inc., Cambridge, Mass., as assistant foundry superintendent.

Carpenter Steel Co. announces the appointment of CARL O. ERICKE ⊜ as district manager of the Detroit territory. He has been with the company as sales engineer since 1934.

A. J. NORDENSON ⊜ is now associated with J. T. Thorpe, Inc., Los Angeles, handling engineering and sales.

CAPT. R. K. WELLS ⊜, U. S. N., has recently been transferred from Terminal Island, Calif., and is now industrial manager, 8th Naval District, with offices at New Orleans.

ROBERT B. SMOCK ⊜ has been promoted to physicist P-2 in Aviation Ordnance Dept. of Naval Proving Ground, Dahlgren, Va.

A. PHILIP BUNK ⊜, formerly associate welding engineer at New York Navy Yard, is now research engineer in the electrode division of the Metal and Thermit Corp. in the research and development laboratory in Woodbridge, N. J.

ROBERT L. SPRINGER ⊜ has returned to Vanadium-Alloys Steel Co. as engineer and representative in Chicago. He was formerly with the Rustless Iron & Steel Co. and Geary Stainless Steel Co.

RICHARD P. SEELIG ⊜ has joined the staff of the American Electro Metal Corp., Yonkers, N. Y. He was formerly connected with Powder Metallurgy Corp., Long Island City.

WILSON N. PRATT ⊜, formerly with American Electro Metals Corp., has been appointed to supervise all powder metallurgical engineering activities of Charles Hardy, Inc. He replaces J. J. CORDIANO ⊜, who resigned to join Butler Bros. to continue with the development of electrolytic iron.

CARL I. SCHWEIZER ⊜, chief metallurgist for Steel Improvement & Forge Co., Cleveland, has been placed in charge of the new turbine forgings division of the company.

J. W. BURDICK ⊜ has been named sales manager, New York district, for the Washington Steel Corp., Washington, Pa. He has been associated with steel sales work in New York and New England districts since 1938.

M. E. FINE ⊜, formerly with the Manhattan District Project at Los Alamos, has become a member of the technical staff of the Bell Telephone Chemical Laboratories, Murray Hill, N. J.

JAMES C. HARTLEY ⊜ has been appointed chief metallurgist for Barium Steel & Forge, Inc., Canton, Ohio. He was formerly director of research at Heppenstall Co., Pittsburgh.

FOR TOP PRODUCTION OF CASTINGS AND INGOTS

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ELECTRIC

MELTING FURNACES

Top charging

Effective gantry design combined with platform attached to furnace for minimum maintenance and maximum efficiency of operation.

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General Offices: Frick Building, Pittsburgh, Pa.

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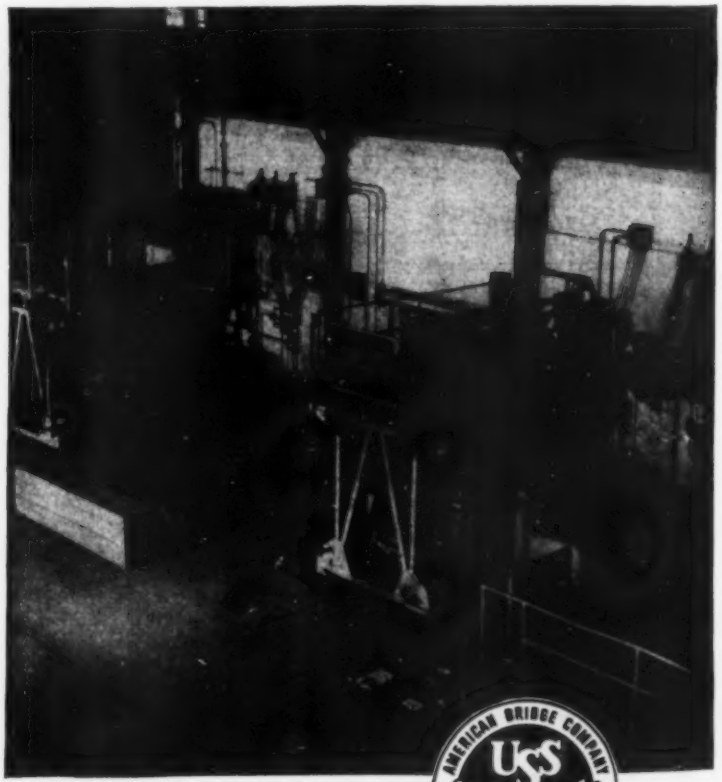
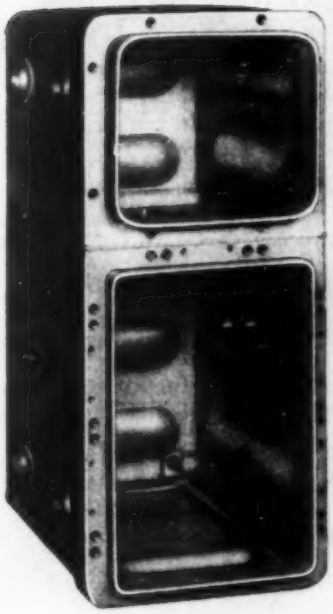
Columbia Steel Company, San Francisco, Pacific Coast Distributors
United States Steel Export Company, New York



UNITED STATES STEEL



How WELDING SOLVED A HOUSING PROBLEM

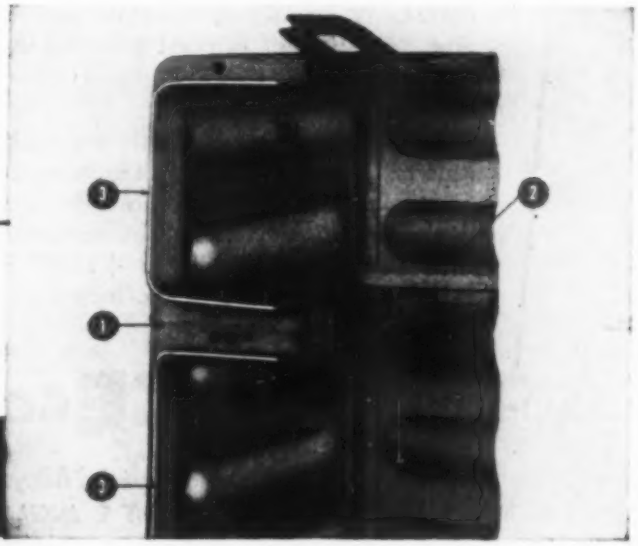
This aluminum radio-housing was successfully welded by the INERT-ARC process — WITHOUT FLUX!

The Problem—To fabricate, on a production basis, *watertight* aluminum cases for naval radio equipment. Welding seemed the most logical solution, but there were several types of "difficult" joints, some so located that they could not be cleaned effectively on the under side. Thus, in addition to being absolutely watertight, the welds had to be made *without the use of any flux whatsoever.*

The Solution—Investigation demonstrated that this job could be successfully welded using the G-E Inert-Arc process. (Inert-Arc welding is particularly adapted to light-gage and other so-called "difficult" metals—aluminum, cold-rolled steels, copper and special alloys, stainless, etc.)

Six equipments were designed for the application, each utilizing the small, light-weight G-E Type WGS electrode holder to facilitate reaching the difficult joints inside the case. In short order, the housings were being successfully production welded—each with approximately 43″ of lap joints, 75″ of edge welds, and 140″ of butt joints.

Results—An improved housing was produced in less time and at lower cost—those ever desirable advantages. Perhaps you can enjoy some or all of them in a welding operation of your own; your nearest G-E Arc-welding Distributor is eager to demonstrate how! *Apparatus Department, General Electric Company, Schenectady 5, N. Y.*

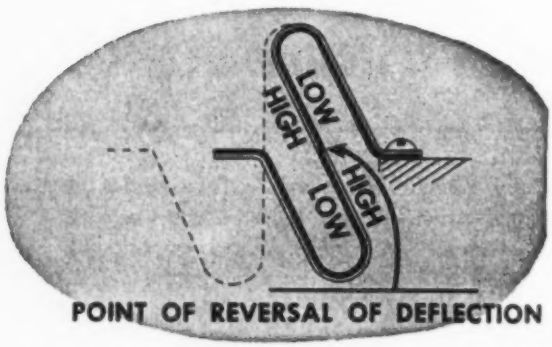


This cut-away view gives only a suggestion of some of the difficulties involved.
1. Butt weld
2. Interior lap weld
3. Edge weld (watertight)
Resistance spot welding was also used.

GENERAL ELECTRIC

HOW BIMETAL PRODUCES Automatic ACTION

Some controls require "straight-line" movement of the thermostatic bimetal element. The shape illustrated is frequently used in such applications.



POINT OF REVERSAL OF DEFLECTION

The original bimetal strip is cut in half, reversed and the ends welded together as one piece. In this construction the higher coefficient of expansion side of the bimetal is on the inside of each U shape. When the temperature rises, the element opens out, automatically delivering a pushing force at the free end. Cooling of bimetal reverses the movement.

Chace thermostatic bimetals are available in 35 types for use in temperature operated controls; these bimetals meet every condition within the temperature range of —100° F. to +1200° F. Available in sheets, strips, forms and sub-assemblies.

W.M. CHACE CO.
Manufacturers of
Thermostatic Bimetals and Special Alloys
1626 BEARD AVE. • DETROIT 9, MICH.

Personal Mention

ROBERT R. RAWSTRON has been appointed manager at the Delisle Machine Co., New Hartford, Conn. He was formerly with the Norton Co. and Worcester Taper Pin Co. of Worcester, Mass.

ARCHIE L. WALTERS has joined the staff of Battelle Institute and will be engaged in research in the steel processing division. He was formerly metallurgist with International Harvester Co., Springfield, Ohio.

J. M. G. FULLMAN has retired as general design engineer of National Electric Products Corp. after 33 years of service, with more than a third of this time as works manager of the Ambridge, Pa., plant.

Driver-Harris Co., Harrison, N. J., announces the appointment of GEORGE A. LENNOX as vice-president in charge of sales and JOSEPH B. SHELBY as assistant vice-president in the same department.

R. J. RICE, metallurgical and chemical engineer, has been placed in charge of the newly opened Texas technical section of the development and research division, International Nickel Co., Inc.

R. W. PRICE of the Norton Co. has been appointed district manager of the Connecticut area by the abrasive division.

DONALD A. POTTER, discharged from the Navy in February, has been appointed research and development engineer for Universal Castings Corp., Chicago. During the war he did research in the Division of Physical Metallurgy at the Naval Research Laboratory, Washington, D. C.

JOSEPH N. PETERS has been named manager of the carbide and cast alloy division of the Jessop Steel Co., Washington, Pa.

W. H. BRANDT, formerly manager of the materials engineering department, has been appointed manager of the new Westinghouse special products engineering department.

The appointment of HENRY A. MULLEN as manager of resistance welding sales has been announced by Ampco Metal, Inc., Milwaukee. He was previously connected with the Ford Motor Co. at Willow Run as welding engineer.

R. R. ELSASSER, formerly manager of Timken Roller Bearing Co.'s Newton Falls plant, has been appointed assistant superintendent of tube mills. He has been with the company since his graduation from Ohio State University in 1935.

REGINALD S. DEAN, former assistant director of the U. S. Bureau of Mines, announces that he is engaging in private practice as a metallurgical engineer and consultant specializing in electrometallurgy and alloys with offices and laboratory in Washington, D. C.

WILLIAM R. EDGERTON is now metallurgical engineer for the Penfield Saw Works, Inc., Bristol, Conn.

ALBERT F. SATTERTHWAITE has moved to Los Angeles, and is engineering and sales representative for Holcroft & Co. of Detroit and Industrial Heating Equipment Co. and Carl Mayer Corp. of Cleveland.

Steelmaking Practice as it Affects Properties of Interest to the User

By Charles H. Herty, Jr.
Asst. to Vice-President
Bethlehem Steel Co.
Bethlehem, Pa.

CONSUMERS of steel are variously interested in a multitude of its properties, some well known through experience, others in various stages of investigation and development. Fortunately, only a limited number of properties are required of any given part made of steel.

In the early days of the industry, steel was furnished in three grades — soft, medium and hard. The three grades fulfilled most of the commercial needs for steel at that time and the steelmaker produced any of these grades depending upon what he knew of the requirements of the product. The terms "soft", "medium" and "hard" included the strength and ductility factors which were required by engineers of the time. As the properties of steel became better known and as the effects of composition on these properties were studied, the consumer began to order steel either to physical properties or to chemical specifications, and sometimes to a combination of both. Over the past 30 years there was a pronounced swing toward the procurement of steel through chemical specifications, and from these specifications consumers and producers arrived at a series of standard steels which have been widely used. Now, however, the trend is beginning to reverse itself and more and more people — both producers and consumers — are thinking of steel in terms of its suitability to fulfill physical requirements rather than to meet an exact analysis.

In order to produce a steel to meet the requirements listed above, the steelmaker must

1. Produce the analysis desired or specified.
2. Assure the required degree of soundness and homogeneity.
3. Meet the physical properties required.
4. Produce a part which will react to various treatments or conditions in the manner expected.

The most important steelmaking practices which are necessary to fulfill these four conditions are *(a)* composition control; *(b)* its adjunct, slag control; *(c)* deoxidation; and *(d)* rolling mill operations. The first three of these are interrelated and in the most successful melt shops all three are intensively followed. The fourth is important when as-rolled material is involved. Pouring practice and ingot mold design are also important factors in steelmaking, but are not discussed in this paper.

Composition Control — The use of magnetic or other methods for quickly measuring the carbon content of the liquid bath has enabled the operator to provide steel within a closer range of carbon content than was possible in earlier days. It has also eliminated the necessity for the long deoxidation period which was formerly necessary in order to obtain reasonable accuracy. In present-day practice, the carbon content of the bath can be determined within about 2 min. from the time a sample is taken from the furnace, and, as can well be imagined, this is of inestimable help to the melter.

Chemical analysis of metal and slag has been developed both in speed and accuracy over the past 20 years. The spectroscope is now used in many plants for the analysis of all elements except carbon, phosphorus and sulphur; a complete analysis of the bath, except phosphorus and sulphur, can be obtained in about 15 min.

The control of nonoxidizable elements such as nickel, molybdenum and copper depends on the accuracy of the preliminary chemical determinations when the heat is melted, upon the accuracy

of the estimation of the weight of the heat, and the efficiency or recovery of the final additions. In these controls the spectroscope has helped very greatly in that any desired number of determinations of the bath content of the above elements can be made during the course of the heat.

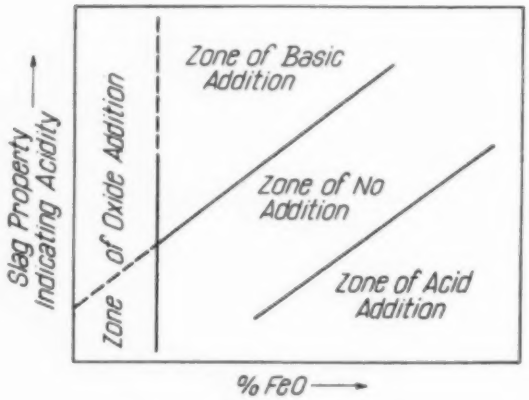


Fig. 1 — Correction Chart for Basic Openhearth Slags

Composition control with respect to the oxidizable elements manganese and chromium is primarily a function of the accuracy of estimating the residual content in the bath, the efficiency of the slag control system, the perfection of the deoxidation practice, and the skill of the melter.

Phosphorus and sulphur control are best accomplished through one of the many slag control systems in use.

Slag Control — Slag control, when properly carried out by any one of a number of methods, yields a finished slag of a rather closely controlled composition with respect to lime, silica and iron oxide. The most important means to this end is the physical and chemical uniformity of the raw materials; if there is sufficient uniformity, slag control becomes practically automatic.

At the present time, this happy state of affairs seldom occurs and, especially in hot metal shops, some control system is necessary. There has been much active development work along this line during the past 20 years, and at the present time the pancake test — visual examination of the surface of a pancake-shaped sample of freshly poured slag, and its comparison with standard samples — is probably the most widely used by melters of basic steel. In many acid steel shops, slag viscosity measurements have proven to be very useful in estimating slag composition. Figure 1 shows the general principle of almost all slag control systems; corrective additions are based upon some test which shows the condition of the slag with respect to composition. Figure 2 shows a viscosity test being poured.

For any degree of basicity and FeO content of the slag at any time during the course of the heat there is a fairly narrow range of finishing slag composition. Hence, after the proper test is taken it is possible to make corrections by the addition of lime, sand or iron oxide to enable the operator to arrive at his desired end point with respect to slag composition. A great deal of careful work must be done in correlating slag composition changes for any given set of raw materials and furnaces before such a system can be put into practical use, but once standard procedures are set, it is possible to regulate finishing slags with a rather high degree of accuracy.

Fig. 2 — Pouring Test for Slag Viscosity

Oxidation — For many years, the oxidation of the metal was generally considered to be controlled by the iron oxide content of the slag. More recent work has indicated that the carbon content is controlling — except at low carbons, when the slag oxidation exerts a marked effect. From the standpoint of metal *oxidation*, slag control is, therefore, more important on low carbon heats. How-

ever, the fact that considerable variations in characteristics, thought to be affected by oxidation, occur in high carbon as well as low carbon steels indicates that we should give more attention to the happenings after the heat is blocked or tapped than we have in the past.

Deoxidation — Advances made in deoxidation are interrelated with the increased speed of making carbon determinations, because many deoxidation practices involve a short time interval in the furnace, and this would not be possible without quick and accurate carbon determinations. The three main furnace deoxidizers are ferromanganese, silicon pig and silico-manganese. In some plants, the use of crushed ferrosilicon on the slag just prior to the ferromanganese addition has worked very successfully, and other combinations of special deoxidizers are occasionally used.

For deoxidation in the ladle, the standard elements manganese, aluminum and silicon are most commonly used, but for many special steels other deoxidizers in the form of single or complex alloys have found their definite place in many steelmakers' plants.

Rolling Mill Practice — Under this phase of practice it will only be necessary to mention that in rolling any product, the finishing temperature is controlled primarily by the speed of rolling and the section or mass of the resulting shape. Some variation in finishing temperature can be obtained by an intelligent crew, but the section and the mill generally control the finishing temperature. On certain steels the finishing temperature should be varied somewhat depending upon the property desired; for example, coarse, as-rolled grain from high temperature finishing is used as an aid to machinability.

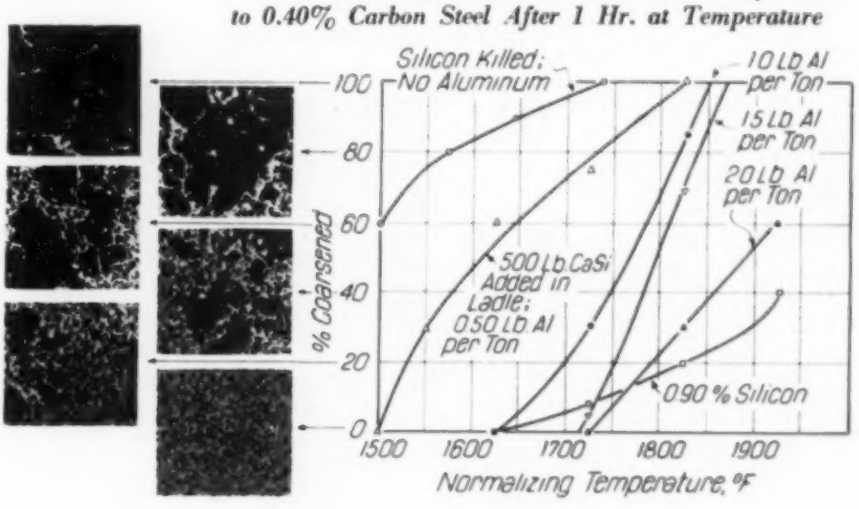


Fig. 3 — Effect of Normalizing Temperature and Aluminum Addition on Austenitic Grain Size of 0.30 to 0.40% Carbon Steel After 1 Hr. at Temperature

Properties

There are so many properties of steel of interest to users that it would be manifestly impossible to discuss many of them in a small space. Among these properties are homogeneity, tensile strength, yield point, ductility, cold forming properties, corrosion resistance, machinability, resistance to shock at various temperatures, weldability, ability to respond to heat treatment — and many others. For the purpose of this discussion, we can choose tensile properties and response to heat treatment as typical properties of interest. In these two particular instances, it must be kept in mind that physical properties depend so much on the analysis of the steel that considerable care must be exercised to avoid incompatible requirements.

Tensile Properties — A tremendous amount of information has been made available in the past decade on the influence of various elements on the physical properties of steel in the as-rolled and in the heat treated condition. These properties in as-rolled steel depend largely on the composition and the rolling practices, and the suitability of the product as regards strength requirements depends upon the steel mill's ability to coordinate the two. Not so many years ago, the steelmaker was dependent on the skill of the individual melter to produce an analysis which would give the desired property. More recently, the use of magnetic methods of measuring the carbon content of the steel while it is yet in the furnace, more rapid methods of chemical analysis for other elements, the use of the spectroscope, and the wide adoption of various slag control methods used in conjunction with up-to-date methods of deoxidation, have given a much closer control of the strengthening elements than before these tools were available.

The effect of residual elements on the mechanical properties of as-rolled steel is of considerable interest at the present time. The use of the spectroscope for the determination of residuals controls these elements so their presence may be properly taken into account in the balance of the analysis or in the diversion of the heat to other uses where *(a)* they would not adversely affect the properties, or *(b)* where advantage can be taken of their presence. It must be borne in mind that it is not alone the analysis of the steel which determines the as-rolled properties but also the

rolling conditions, and these two in conjunction determine the steelmaking practice which eventually is translated into a piece of steel with useful properties.

There is a rising interest at the present time in as-rolled steels which have a much higher yield point and tensile strength than ordinary carbon steels. These enhanced mechanical properties must be obtained without appreciable loss of ductility or weldability (and generally with increased corrosion resistance). In these steels, the producer has generally made use of moderate additions of the proper alloying elements. At the same time, the steels are usually produced in such a fashion that they will not lose toughness at low temperatures as rapidly as ordinary steels. The latter is accomplished by the use of strong deoxidizers such as aluminum which tend to lower the critical temperature at which the type of fracture changes from ductile to brittle when tested in impact. There is still much to be learned along this line, but remarkable strides have been made in the development of these low alloy, high tensile steels, and I think it safe to predict that they will become even more popular as more and more is learned about their behavior.

Heat Treatment — One of the outstanding examples of the effects of steelmaking practice is the advancement of the art of producing steels for desired response to heat treatment. During World War I and shortly thereafter, a great deal of work was done on the use of aluminum to produce fine-grained steels. The literature contains a high percentage of papers dealing with grain size, and the steelmaker has carried out extensive work on the effect of deoxidation on the grain size of the resultant steel and on the production of fine-grained steels.

Figure 3 shows the effect of aluminum additions of various amounts on the coarsening characteristics of 0.30 to 0.40% carbon steel as the normalizing temperature goes up. This shows the profound effect of deoxidation practice on grain growth. Each line on the chart is the average of at least 25 commercial heats made in 130-ton basic furnaces. Apparently, the major part of the restraint of grain growth is accomplished with about 1 lb. of aluminum per ton. It is interesting to note that 1.0% of silicon has about the same effect as an aluminum addition of about 2 lb. per ton.

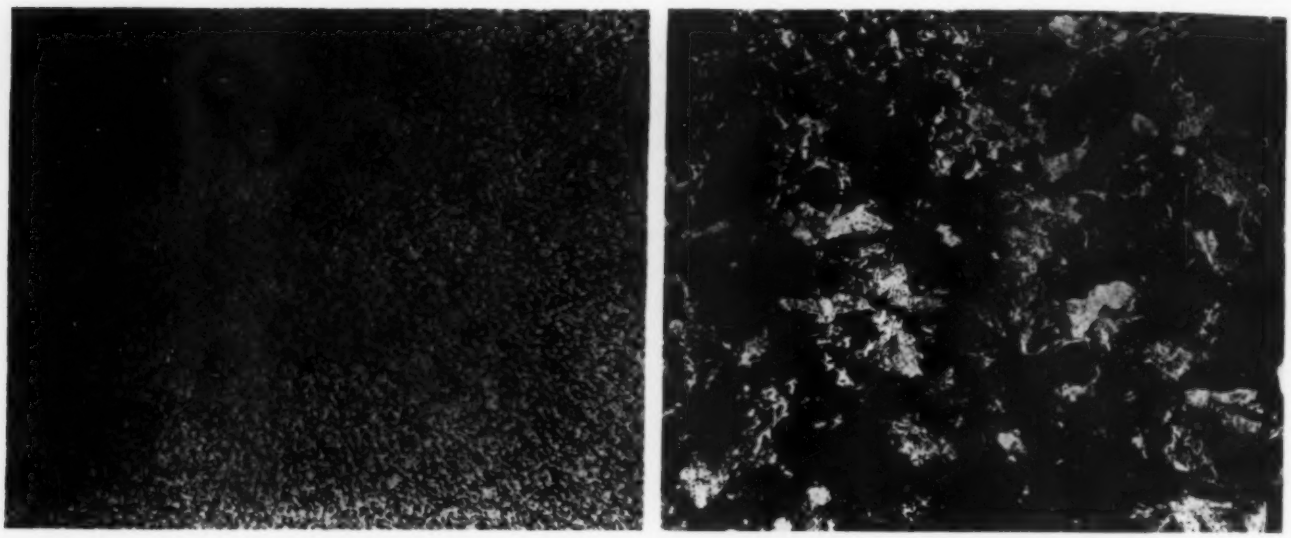


Fig. 4 — Microstructure of Two Normalized Steels, Induction Melted, the Fine-Grained One Melted and Solidified Without Protective Atmosphere, the Coarse-Grained One in an Atmosphere of Hydrogen

Composition	Fine Grained	Coarse Grained
Carbon	0.46%	0.47%
Manganese	0.13	0.12
Aluminum	0.071	0.082
Aluminum added	0.10	0.10

So much for the effect of aluminum in practice. An intensely interesting observation on the role of aluminum in the production of fine-grained steels is found in Fig. 4, which shows the grain structure of two normalized samples of almost identical composition (induction melted) different only in that one sample was melted and solidified normally, while the other was at all times in an atmosphere of hydrogen. In the former, the usual fine-grained structure is revealed; the latter is completely coarse grained. This indicates that aluminum in the absence of oxygen has no restraining effect on grain growth at the tempera-

tures involved, and emphasizes the necessity for control of oxidation and deoxidation in connection with the aluminum addition.

Practically all alloy steels today are made fine grained. There are a few exceptions where certain properties, among them machinability, are of prime importance. The steelmaker has had to resort to great refinements in finishing practice and in his choice of deoxidizers in order to produce the required grain size together with other

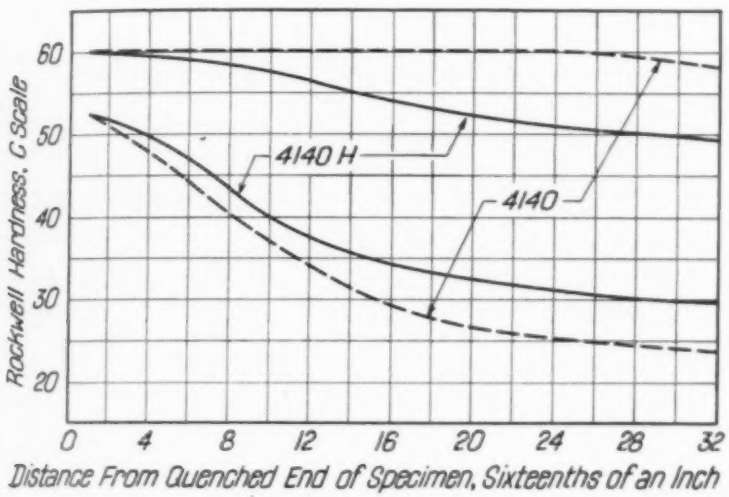


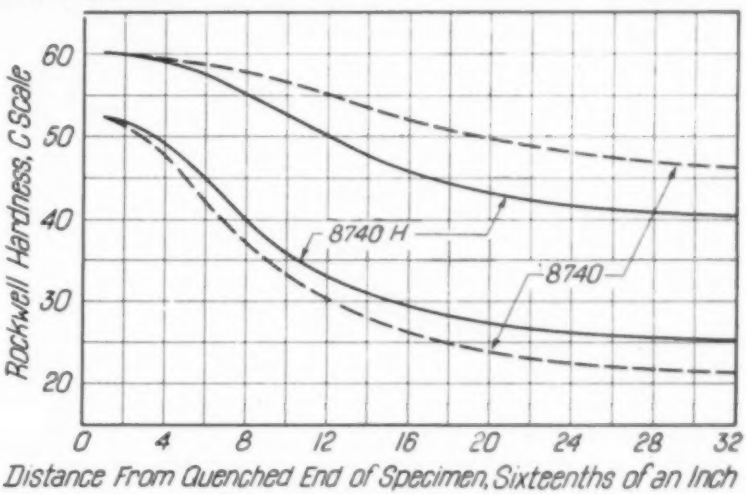
Fig. 5 — Hardenability Bands (Limits, High and Low) for Composition Spread of 4140 and 4140H Steels; Fig. 6 (Right) — Same Information for 8740 and 8740 H

requirements, such as soundness under the magnetic particle test — to mention but one. Such practices have involved a choice of strong deoxidizers, the degree of deoxidation of the bath in the furnace, and a very careful control of the slag to insure that the inherent grain size characteristics of the steel in the ladle will not be upset during the teeming of the heat.

Inasmuch as the majority of alloy steels are of the fine-grained type, it is possible to study the hardenability characteristics of alloy steels, with one major variable eliminated. A great many special types of tests have been introduced in an effort to determine this quickly and accurately, but it remained for Walter E. Jominy, the winner of the 1944 Sauveur Achievement Award, to develop a simple test by means of which the hardening characteristics of a heat of steel could be readily predicted. This Jominy test has been widely used and, by its proper interpretation, the depth to which a given analysis of steel will harden is now predictable. It is further possible to calculate the variations in hardenability that will be developed in a steel of a given range of composition in alloying elements. Thus we can know rather accurately in advance what the range of hardenability will be with a given range of chemical composition. From this it is a simple step from specifying a steel by its chemical limits and obtaining a corresponding variation in hardenability, to determining the limits of hardenability which are desired and then allowing the steelmaker to produce this steel in a certain characteristic grade.

Steps are now being taken along this line, and the American Iron and Steel Institute's Steel Products Manual, Section 10, June 1945, is representative of this change from ordering by chemical to physical specifications. The standard chemical limits have been slightly widened for certain elements in these "H Band" steels, in order to enable the steel producer to adjust the final analysis to the melting conditions and to compensate for variations in practice often made necessary by local conditions, particularly with respect to residual alloys.

Figures 5 and 6 show hardenability



limits for two popular grades of steel: 4140 and 8740. A comparison of the analyses of 4140H and 8740H with the standard ranges is as follows:

	4140	4140H	8740	8740H
C	0.38/0.43	0.37/0.45	0.38/0.43	0.37/0.45
Mn	0.75/1.00	0.70/1.05	0.75/1.00	0.70/1.05
Si	0.20/0.35	0.20/0.35	0.20/0.35	0.20/0.35
Ni	—	—	0.40/0.70	0.35/0.75
Cr	0.80/1.10	0.80/1.15	0.40/0.60	0.35/0.65
Mo	0.15/0.25	0.15/0.25	0.20/0.30	0.20/0.30

The dotted lines on the charts show the maximum

and minimum Jominy curves which could be obtained if all elements were either on the high or the low side of the standard specification. If the nonoxidizables are above or below the mean of the standard ranges, adjustment may be made in the "H" analysis in manganese and chromium, and under these conditions, the extremes in the Jominy curves can be avoided. The solid lines on the charts are the "tentative hardenability limits" which the producing industry has set up, when allowed the leeway in composition shown in the "H" analysis.*

In such a change (as in any other) in a specification involving physical properties for a type of steel, the steelmaking practice is of utmost importance, and here the steelmaker must call upon all his resources in the way of chemical practice, slag control and deoxidation practice in order to produce a satisfactory product for the consumer.

Some Wartime Problems

It would be amiss at this time not to take up briefly the question of "steelmaking practice of interest to the user" as reflected in the events of the past five years. It must be remembered that at the outbreak of the war we were cut off from many materials of which we had always had a plentiful supply. In addition, we had to increase our facilities to produce greater tonnages of all grades of steel, and with these greater tonnages to call for larger quantities of raw materials which had been supplied from this country alone. At the same time, it was essential that the quality of our steel be unimpaired and that no discontinuity should occur in our supply of steel products. Various American Iron and Steel Institute subcommittees were active in the conservation measures outlined in the following paragraphs.

Iron Ore in the Openhearth — Increased requirements of steel ingots were to a considerable measure met by an increase in the amount of pig iron which was produced through the building of new blast furnaces. This increased the pig iron content of the openhearth charge, and this required a much larger amount of iron ore of suitable quality for use in the openhearth to oxidize the extra carbon brought into the charge by the pig. It was at once apparent that our normal supplies of lump ore would not see us through. A subcommittee consisting of openhearth operators explored means of overcoming this shortage, and methods were devised to utilize large quantities of certain soft ores which previously had been considered unsuitable. This was accomplished by determining their limitations for direct use and by processing them in rotary kilns. The limiting factors on the use of soft ores were, *(a)* that there should not be more than about 7 lb. of combined water in the ore per ton of steel, and *(b)* not more than about 15 lb. of silica per ton of steel. With these two limitations, it was a simple matter to determine the amounts of soft ore which could be used in the charge from the silica analysis and ignition loss of the ore. There was also an increase in the use of nodulized and sintered ore.

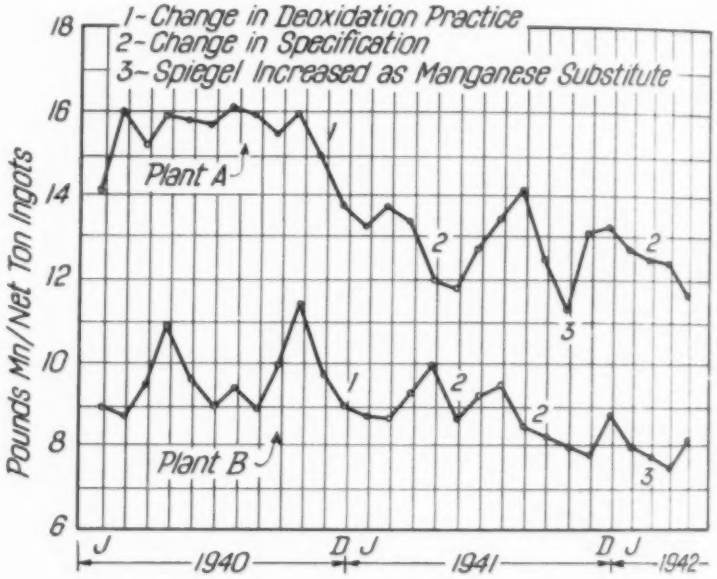


Fig. 7 — Manganese Consumption in Two Plants, Month by Month, During the Early Years of the War, Showing the Effect of Various Conservation Measures

These three steps served to solve the problem of openhearth iron ore shortages which at one time appeared to be very serious.

Aluminum — In 1940, the demands for aluminum for aircraft and other uses became so great that the steel industry was asked to curtail its aluminum consumption considerably, so again a subcommittee of steel plant metallurgists met to consider this problem and the use of lower grades of aluminum. As a result of these studies, the aluminum consumption in the industry dropped from 0.698 lb. per ton to 0.562 lb. per ton. While this does not sound like much it amounted to over 5000 tons of aluminum in the 80 million tons of steel produced in one year. This aluminum situation, although tight over *(Continued on page 826)*

*A complete set of hardenability bands for the "H" steels can be found in "Metal Progress Data Sheets" (1946 Edition), No. 19 to 24.

By A. O. Schaefer
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Control of Quality in Steel Manufacture*

PRODUCTION during the past war period was a problem of quality as well as quantity. From 1935 to 1945, total steel production per year was more than doubled, but alloy steel production (which accounts for a relatively small portion of total) increased by five times. Furthermore, most of the wartime steel was produced to rigid specifications imposed by the armed forces, whereas in peacetimes a relatively small amount of the steel production is so governed.

Another significant figure that might be noted is the increase in electric steel production; this multiplied almost nine times. It is easily seen, therefore, that the steel industry was called upon to produce to a rising quality level during a period when production was the maximum that could be obtained.

Quality control is not new. High quality steel is not new. The metal craftsmen of 40 or 50 years ago produced steel in many ways as fine as ever made. What may be considered to be new is the production of *quality steel in quantity*, or rather a large quantity of steel of known quality level, of known reliability.

Practical necessity has driven us to develop ideas on process control, to revise our methods of testing and sampling, and to apply the best of our metallurgical knowledge to this phase of metal production.

The job has been accomplished in a number of ways. We will speak later of the application of statistical analysis for eliminating unnecessary testing. At the same time, new and revealing inspection tools have been devised and applied extensively.

The change in our thinking on this subject has been most significant. "Testing and inspection" have for a long time been an important subject for consideration. "Quality control" is now to the front, and perhaps more frequently mentioned than the older terms. Actually both of these expressions are used to denote the efforts to produce a satisfactory product for the job intended. The philosophy we are to discuss is more interested in reaching and maintaining a certain quality level without serious departures from it, than in producing large quantities of material and *then* establishing its quality by tests and inspection.

I hesitate to use the word "quality" in this sense because to some it has commercial implications. However, we will have to use it. We have long talked of "toolsteel quality", and for a number of years now of "aircraft quality". It is increasingly recognized that these qualities do not necessarily represent ascending steps on a ladder. They do indicate the fact that the requirements of the steel for one job differ from the requirements of steel for another job. "Toolsteel quality", in the sense that it means a dense and clean steel, would not be the first selection for many structural applications. Contrariwise, "aircraft quality", which is undoubtedly of the utmost reliability in the service for which it is intended, is definitely not the quality one would specify in toolsteel.

We have found, for example, that steel for gun barrel forgings, which are to be thoroughly tested in a transverse direction, requires certain characteristics which may be of little or no value in other applications — connecting rods, for example. Again, welding quality steel, in addition to

*One of the papers presented by Philadelphia Chapter ⊖ last winter in a symposium on quality control.

being fairly low in carbon and free of excessive alloying elements, needs also for some applications to resist graphitization after prolonged exposure at elevated temperatures.

We can then divide the job of quality control into two phases — one being the recognition and control of the factors of manufacture which affect the desired quality. We will discuss this before considering the second, which comprises tests and inspection.

Recognition of Manufacturing Factors

Leo Reinartz, in his Howe Memorial Lecture of 1943, defined practical quality control as follows: "By *positive* control of quality is meant that form of management or direction which establishes the quality requirements, then sets up the organization, and selects the personnel capable of securing that quality. By *continuous* control of quality is meant the vigilant maintenance and direction of organization and personnel setup to make that control positive."

Here is expressed the salient points of quality control. It cannot be effective if it is to be merely a policing effort by one department in a plant. Basically it must be a part of company policy. It is achieved through the closest cooperation between the metallurgical and the production departments. The active interest of management is essential.

The actual mechanics of quality control in steel manufacture consist fundamentally of process specifications or standard practices to be followed in all operations. These must be supplemented by a corps of observers who note in detail the actual practices in the shops. Considerable care must be taken to record these observations. Patience and knowledge must be applied to analyze them on the basis of the results obtained. We will consider first some of the factors to be observed and the means of doing it.

If we start with melting, we can say that the steel melter, as well as the other technicians, now has improved measuring tools. The instrument panels of a modern melting furnace compare with those of an airplane for number of dials. Immersion thermocouples, which are practical at the high temperatures encountered, have been developed and their use extended. Improvements have been noted in the methods of analyzing steel, enabling the melter to know promptly the composition of his bath. Use of the spectrograph has spread throughout the steel plants of the country and has contributed to this, in addition to other fast methods, particularly for the measurement of carbon content.

The tremendous increases in amount of alloy and electric furnace steels have increased the use of big-end-up, hot top, ingot molds. Furthermore, the inspection of hundreds of thousands of polished gun barrel bores, together with the charting of the nonmetallic inclusions found in them, has led to constructive thought on the design of ingot molds which can be expected to yield much fruit in future years. This may be cited as only one example of the value of experience with great numbers of examples — when the time is taken to arrange the data and to evaluate them. Ingot mold design has yet a long way to go, but it is not improbable that we shall arrive at a time when — to an even greater extent than now — ingot molds are tailor-made to fit particular jobs.

Among the other tools that have been utilized by the melter should be mentioned several means of prolonging the liquidus-solidus period in the metal in the hot top, either by ladle additions, or by arc heating of the hot top, thereby reducing the sink head cavity and increasing the yield per ingot. This may affect quality, and further study will doubtless be given the subject.

Viewing the field of mechanical working from the equipment standpoint, it will be noted that various types of optical pyrometers have been largely used to observe work in process; automatic temperature control and furnace atmosphere control have also been installed on heating furnaces.

Sound Forgings

Considerable study has been directed to the subject of forging reduction. Some old specifications (some still in existence) specify a minimum reduction from ingot to forging of 5 to 1. This was of particular importance in the manufacture of gun barrel forgings, since the amount of reduction by forging may be assumed to have an effect upon the ductility obtained in transverse test bars. It has been established, however, that excessive forging reduction, particularly when the work is done in the lower range of temperatures, lowers rather than improves such ductility. Very satisfactory forgings have been made with minimum reductions, when the metallurgist is sure of the soundness of the ingot used, and carefully avoids the increased risk in thermal cracks and quenching cracks. On the other hand, extremely fine transverse ductility has been obtained in forgings with very high over-all reductions from ingot to forging, providing the steel is melted in the proper way, either by aiming for extreme cleanliness, or by controlling the size, distribution and form of the nonmetallics.

In the handling of material after hot mechan-

ical working, there is one particularly important item in quality control for sound forgings. Thermal cracks or flakes are undoubtedly caused by internal stresses set up by temperature gradations from surface to center in the cooling of masses of metal. They result in ruptures because the structural condition of the metal cannot withstand the stresses imposed, or because the structure is weakened by some such auxiliary cause as the evolution of hydrogen. Thermal cracks are more apt to occur in these steels in which the transformation range on cooling is considerably depressed, because the stresses incident to transformation are imposed at about the time any contained hydrogen is expelled from solution. They are more apt to occur in electric furnace steel than in openhearth, because the hydrogen content of the former is usually higher. They are more apt to occur in large masses than in small masses because the differential stresses are correspondingly larger. They seem to be sensitive to forging reduction to the extent that a certain amount is apparently necessary to consolidate the central portion of the metal mass so that it may withstand the stresses imposed.

At any rate, the handling of materials subject to this type of defect is extremely critical, and metallurgical control is absolutely necessary if one would avoid trouble from this very subtle and harmful defect.

The means of avoiding flakes are principally slow and controlled cooling from the mechanical working temperature. Ingots or forgings may be cooled in pits filled with insulating material; metallurgical control must see to it that pieces are well buried, that there is sufficient bed to insure a slow enough cooling rate, and that the pieces are left undisturbed in the insulating material until they are safely below the dangerous temperature. Should the practice be to transfer the material directly from the mechanical operations to the treatment furnace, metallurgical control is necessary to see that the piece is charged into the reheating furnace before it has cooled too far, and

Levermen in the Forge Shop

Photo by John P. Modd

to see that the heating and cooling cycle is designed to avoid the defects.

Much emphasis has been placed upon "Jominy hardenability" during the war period. Equal attention has been devoted to the S-curves of the materials used. To obtain maximum ductility in transverse tensile test bars, and also to obtain maximum impact characteristics in a transverse direction in steel for certain highly stressed forgings, it was found that the transformation on quenching must be, as largely as possible, direct from austenite into martensite. Transformation at higher temperatures, leading to intermediate products, results most definitely in lower impact characteristics. From these facts has developed the general practice of drastic quenching some classes of forgings, and doubtless this will extend to other products in the peacetime years. Steels such as S.A.E. 4340 are now often water quenched — systems of water cooling and agitation had been installed for the most effective quenching of gun barrel forgings. Undoubtedly extremely drastic quenching increases the risk of cracking, but this may be controlled in other ways, and the resultant product is so greatly improved in mechanical test properties that there is no doubt but that the practice will be continued. Metallurgical control must take full cognizance of the conduct of all heat treating operations — particularly the conditions of quenching.

Equipment for Testing and Inspection

Radiographic inspection has increased notably. We entered the war period with a few million-volt X-ray tubes. We emerged with many million-volt tubes and a scattering of 2,000,000-volt tubes. This latter instrument produces rays that will penetrate 12 in. of steel and give a good film in a relatively short time and with good sensitivity. Since uniformity and reliability are prime requisites in steel as well as in other engineering products, it would seem that tools which so thoroughly reveal the interior of metal objects will be increasingly used for our peacetime demands.

Simultaneously with the development of X-ray tubes, we have seen the more widespread use of radium capsules for the examination of steel. Discovery of more extensive radium deposits in Canada has made more radium available to industry, and this has been used in larger capsules, with a consequent saving of time and with increased sensitivity of the test. [Undoubtedly the near future will see the use of other and more active isotopes from the uranium and plutonium piles as a source of penetrating rays for subsurface inspection of metals, parts and assemblies.]

Brinell

Photo by John P. Mudd

Magnetic particle inspection has increased by leaps and bounds; it now forms an invaluable part of inspection routine. We have, during the war period, used austenitic steels in quantity which, of course, cannot be inspected by magnetic methods. "Zyglo" has been applied to these nonmagnetic materials, especially for inspecting austenitic steel parts for aircraft. Both magnaflux and Zyglo are in reality quicker and easier applied than deep etching techniques, and the indications they give are just as definite. Consequently they have been applied at the billet stage or at other intermediate stages of steel manufacture, and are proving very valuable in the early elimination of defective material.

Supersonic testing has also been rapidly developed in recent years, and is fulfilling the promise predicted of being able to "see"

inside a piece of metal regardless of its size and mass.* The maximum section through which this equipment can be properly used is not yet established, but we know from experience that it is sensitive and accurate in pieces of 8 to 10 in. in thickness. At the other end of the dimensional scale, the reflection of ultrasonic rays from the opposite surface has been utilized as an accurate running gage on the thickness of sheet steel passing through the mills. It therefore appears theoretically possible that material of any size can be effectively examined.

Tensile Testing

Something should be said about the transformations which the old reliable tensile test has undergone in recent years. In the first place we have witnessed the extension of autographic stress-strain equipment and hydraulic testing machines to where they are practically universal. Autographic stress-strain charts are invaluable for recording values and comparing material; the shape of the diagram can also be analyzed and some characteristics of the steels diagnosed thereby.

Simultaneously with the increased use of these methods of tensile testing, we have witnessed the firmer establishment of the yield strength as the measure of elastic strength of steels. The older values reported as elastic limit, proportional limit, proof stress or yield point and were always subject to differences of interpretation and measurement. Autographic stress-strain equipment, and the specification of yield strength at a definitely specified offset, has enabled different laboratories to check each other much better, with consequent elimination of confusion.

An interesting sidelight on this subject has been the gradual increase in the percentage offset allowed in measuring the yield strength. For many applications this started out to be 0.01%, and the resulting figure for yield strength was necessarily very close to the proportional limit of the material. However, it is increasingly recognized that there are unavoidable irregularities in the curve of such magnitude that the 0.01% offset yield strength is not always comparable between different laboratories. Thus, we have seen specifications for important items shift from 0.01 to 0.10% offset. In still other applications this has gone as far as 0.2% offset. Engineers have apparently not been handicapped in the design of structures by these larger values, and much confusion and correspondence between laboratories has been avoided.

*See the two articles on American and English equipment in September 1945 *Metal Progress*.

One of the most interesting developments has been the statistical analysis of tensile test results. We produced, during the war, so many hundreds of thousands or millions of certain objects, that great numbers of tests have been made available to the statistician to enable him to make whatever deductions he may. The subject of statistics has always been filled with terms baffling to the average engineer and metallurgist, and it has seemed formidable for that reason. Now, however, this has been considerably simplified — if only by the great amount of discussion that has ensued. By the intelligent use of statistical analysis, and by proper methods of sampling, the amount of tensile testing (and of other types of testing) has been drastically reduced on many critical objects. Statistical quality control requires that lots submitted for group testing conform to certain basic requirements, but when this is met a very few results may indicate the condition *of the lot* with a greater degree of accuracy than older methods utilizing far more testing — even of each individual piece, but of which no statistical analysis was made. The saving in manpower and testing equipment has been tremendous; statisticians will even go so far as to say that the quality of the product has been more certain with a smaller amount of testing.

The possibility that ordnance equipment might be used at extremely low temperatures in the far north, and that high flying aircraft would operate in regions far below zero, led to a study of impact properties at low temperatures. This revealed that some of our material was not thoroughly quenched or that it was temper brittle. This finally led to an appreciation of the value of the impact test as a means of appraising effectiveness of the quench in ferritic types of alloy steels. Results of the Charpy impact tests have been diagnosed by statistical methods (as have the tensile tests mentioned above) and the number of tests has been kept to a minimum.

It can be said that macro-etching still remains one of the most revealing methods of inspection known to the metallurgist, although other methods mentioned in this paper have the advantage of quickness and ease, and are also nondestructive. For the development of new material, and for the inspection of billet stock for uniformity, there is no test which gives so much information as the macro-etch, either of the transverse or the longitudinal section. Macro-etched disks are also most informative in appraising ingot mold designs and melting practices.

It has been mentioned that the inspection of the polished bores of forgings has rendered infor-

(Continued on page 822)

Standard Carbon and Free Cutting Steels

Revised July 1, 1946

Basic Openhearth and Acid Bessemer Carbon Steels

A.I.S.I. Number	Semi-finish	Hot Rolled Bars	Cold Finished Bars	Rods	Wire	C	Mn	P *(c)*	S *(c)*	1946 S.A.E. Number
C 1006	—	—	—	√	√	0.08 max.	0.25-0.40	0.040	0.050	1006
C 1008	√	√	√	√	√	0.10 max.	0.30-0.50	0.040	0.050	1008
C 1010	√	√	√	√	√	0.08-0.13	0.30-0.60	0.040	0.050	1010
C 1012	√	√	—	√	√	0.10-0.15	0.30-0.60	0.040	0.050	....
C 1013	—	—	—	√	√	0.11-0.16	0.60-0.90	0.040	0.050	....
C 1015	√	√	√	√	√	0.13-0.18	0.30-0.60	0.040	0.050	1015
C 1016	√	√	√	√	√	0.13-0.18	0.60-0.90	0.040	0.050	{X1015 } 1016
C 1017	√	√	—	√	√	0.15-0.20	0.30-0.60	0.040	0.050	1017
(e)	√	√	√	√	—	0.15-0.20	0.60-0.90	0.040	0.050	1018
C 1019	√	√	√	√	√	0.15-0.20	0.70-1.00	0.040	0.050	1019
C 1020	√	√	√	√	√	0.18-0.23	0.30-0.60	0.040	0.050	1020
C 1022	√	√	√	√	√	0.18-0.23	0.70-1.00	0.040	0.050	{X1020 } 1022
C 1023	√	√	—	—	—	0.20-0.25	0.30-0.60	0.040	0.050	....
C 1025	√	√	√	√	√	0.22-0.28	0.30-0.60	0.040	0.050	1025
(e)	√	√	√	√	—	0.22-0.28	0.40-0.60	0.040	0.050	1026
C 1030	√	√	√	√	√	0.28-0.34	0.60-0.90	0.040	0.050	1030
(e)	√	√	√	√	—	0.30-0.36	0.60-0.90	0.040	0.050	1033
C 1034	—	—	—	√	√	0.32-0.38	0.50-0.80	0.040	0.050	....
C 1035	√	√	√	—	—	0.32-0.38	0.60-0.90	0.040	0.050	1035
C 1038	—	—	—	√	√	0.35-0.42	0.60-0.90	0.040	0.050	....
C 1040	√	√	√	√	√	0.37-0.44	0.60-0.90	0.040	0.050	1040
C 1041	—	—	—	√	√	0.36-0.44	1.35-1.65	0.040	0.050	....
C 1043	√	√	—	—	—	0.40-0.47	0.70-1.00	0.040	0.050	....
C 1045	√	√	√	—	—	0.43-0.50	0.60-0.90	0.040	0.050	1045
D 1049	—	—	—	√	√	0.43-0.50	0.50-0.80	0.050	0.050	....
C 1050	√	√	√	—	—	0.48-0.55	0.60-0.90	0.040	0.050	1050
C 1051	—	—	—	√	—	0.45-0.56	0.85-1.15	0.040	0.050	....
(e)	√	√	√	√	—	0.47-0.55	1.20-1.50	0.040	0.050	1052
C 1054	—	—	—	√	—	0.50-0.60	0.50-0.80	0.040	0.050	....
D 1054	—	—	—	√	√	0.50-0.60	0.50-0.80	0.050	0.050	....
C 1055	√	√	—	—	—	0.50-0.60	0.60-0.90	0.040	0.050	1055
C 1057	—	—	—	√	—	0.50-0.61	0.85-1.15	0.040	0.050	....
C 1059	—	—	—	√	—	0.55-0.65	0.50-0.80	0.040	0.050	....
D 1059	—	—	—	√	√	0.55-0.65	0.50-0.80	0.050	0.050	....
C 1060	—	√	—	√	—	0.55-0.65	0.60-0.90	0.040	0.050	1060
C 1062	—	—	—	√	—	0.54-0.65	0.85-1.15	0.040	0.050	1062
C 1064	—	—	—	√	—	0.60-0.70	0.50-0.80	0.040	0.050	....
D 1064	—	—	—	√	√	0.60-0.70	0.50-0.80	0.050	0.050	1064
C 1065	—	√	—	—	—	0.60-0.70	0.60-0.90	0.040	0.050	....
C 1066	—	—	—	√	—	0.60-0.71	0.85-1.15	0.040	0.050	{X1065 } 1066
C 1069	—	—	—	√	—	0.65-0.75	0.40-0.70	0.040	0.050	....
D 1069	—	—	—	√	√	0.65-0.75	0.40-0.70	0.050	0.050	....
C 1070	—	√	—	—	—	0.65-0.75	0.60-0.90	0.040	0.050	1070
(e)	√	√	√	√	—	0.70-0.80	0.50-0.70	0.040	0.050	1074
D 1075	—	—	—	√	√	0.70-0.80	0.40-0.70	0.050	0.050	....
C 1075	—	—	—	√	—	0.70-0.80	0.40-0.70	0.040	0.050	....
C 1078	—	√	—	√	—	0.72-0.85	0.30-0.60	0.040	0.050	1078
C 1080	—	√	—	—	—	0.75-0.88	0.60-0.90	0.040	0.050	1080
C 1085	√	√	—	—	—	0.80-0.93	0.70-1.00	0.040	0.050	1085
(e)	√	√	√	√	—	0.82-0.95	0.30-0.50	0.040	0.050	1086
(e)	√	√	√	√	—	0.85-1.00	0.60-0.90	0.040	0.050	1090
C 1095	—	√	√	√	—	0.90-1.05	0.30-0.50	0.040	0.050	1095

Free Cutting Steels

A.I.S.I. Number *(a)*	Semi-finished Products	Bars *(b)*	Rods	C	Mn	P *(c)*	S *(c)*	1946 S.A.E. Number
B 1006	—	—	*(d)*	0.08 max.	0.45 max.	0.07-0.12	0.060 max.	....
B 1010	—	√	*(d)*	0.13 max.	0.30-0.60	0.07-0.12	0.060 max.	....
C 1108	—	—	√	0.08-0.13	0.50-0.80	0.045 max.	0.07-0.12	....
C 1109	√	√	√	0.08-0.13	0.60-0.90	0.045 max.	0.08-0.13	....
B 1111	—	√	√	0.08-0.13	0.70-1.00	0.07-0.12	0.10-0.15	1111
C 1111	—	—	√	0.08-0.13	0.60-0.90	0.045 max.	0.16-0.23	....
B 1112	—	√	√	0.08-0.13	0.70-1.00	0.07-0.12	0.16-0.23	1112
C 1112	—	√	√	0.10-0.16	1.00-1.30	0.045 max.	0.08-0.13	....
B 1113	—	√	√	0.08-0.13	0.70-1.00	0.07-0.12	0.24-0.33	{X1112 } 1113
C 1115	√	√	√	0.13-0.18	0.70-1.00	0.045 max.	0.08-0.13	1115
C 1116	—	√	—	0.14-0.20	1.10-1.40	0.045 max.	0.16-0.23	....
C 1117	—	√	√	0.14-0.20	1.00-1.30	0.045 max.	0.08-0.13	{X1314 } 1117
C 1118	√	√	√	0.14-0.20	1.30-1.60	0.045 max.	0.08-0.13	{X1315 } 1118
C 1120	√	√	√	0.18-0.23	0.70-1.00	0.045 max.	0.08-0.13	....
(e)	√	√	√	0.27-0.34	1.35-1.65	0.045 max.	0.08-0.13	{X1330 } 1132
C 1137	√	√	√	0.32-0.39	1.35-1.65	0.045 max.	0.08-0.13	{X1335 } 1137
C 1141	—	√	√	0.37-0.45	1.35-1.65	0.045 max.	0.08-0.13	{X1340 } 1141
C 1144	—	√	—	0.40-0.48	1.35-1.65	0.045 max.	0.24-0.33	....
C 1145	√	√	—	0.42-0.49	0.70-1.00	0.045 max.	0.04-0.07	1145
C 1151	√	√	—	0.48-0.55	0.70-1.00	0.045 max.	0.08-0.13	1151

NOTE on silicon content: When silicon is specified in standard basic openhearth steels, silicon may be ordered only as 0.10% max.; 0.10 to 0.20%, or 0.15 to 0.30%. In the case of many grades of basic openhearth steel, special practice is necessary in order to comply with a specification including silicon. Acid bessemer steel is not furnished with specified silicon content.

(a) Code for prefix letters:

B is acid bessemer carbon steel.

C is basic openhearth carbon steel.

D is acid openhearth carbon steel.

(b) Specifications are for both hot rolled bars and cold finished bars.

(c) Phosphorus and sulphur are maximum for basic openhearth and acid bessemer steels; sulphurized or phosphorized steels are not subject to check analysis for sulphur or phosphorus.

(d) B 1006 and B 1010 are standard basic openhearth and acid bessemer steels for rods and wire.

(e) This steel was dropped from the A.I.S.I. lists of standard steels dated July 1, 1946.

A.I.S.I Standard Alloy Steel Compositions

Revised July 1, 1946

Openhearth and Electric Furnace Alloy Steels

(Blooms, Billets, Slabs, Bars and Bar-Strip)

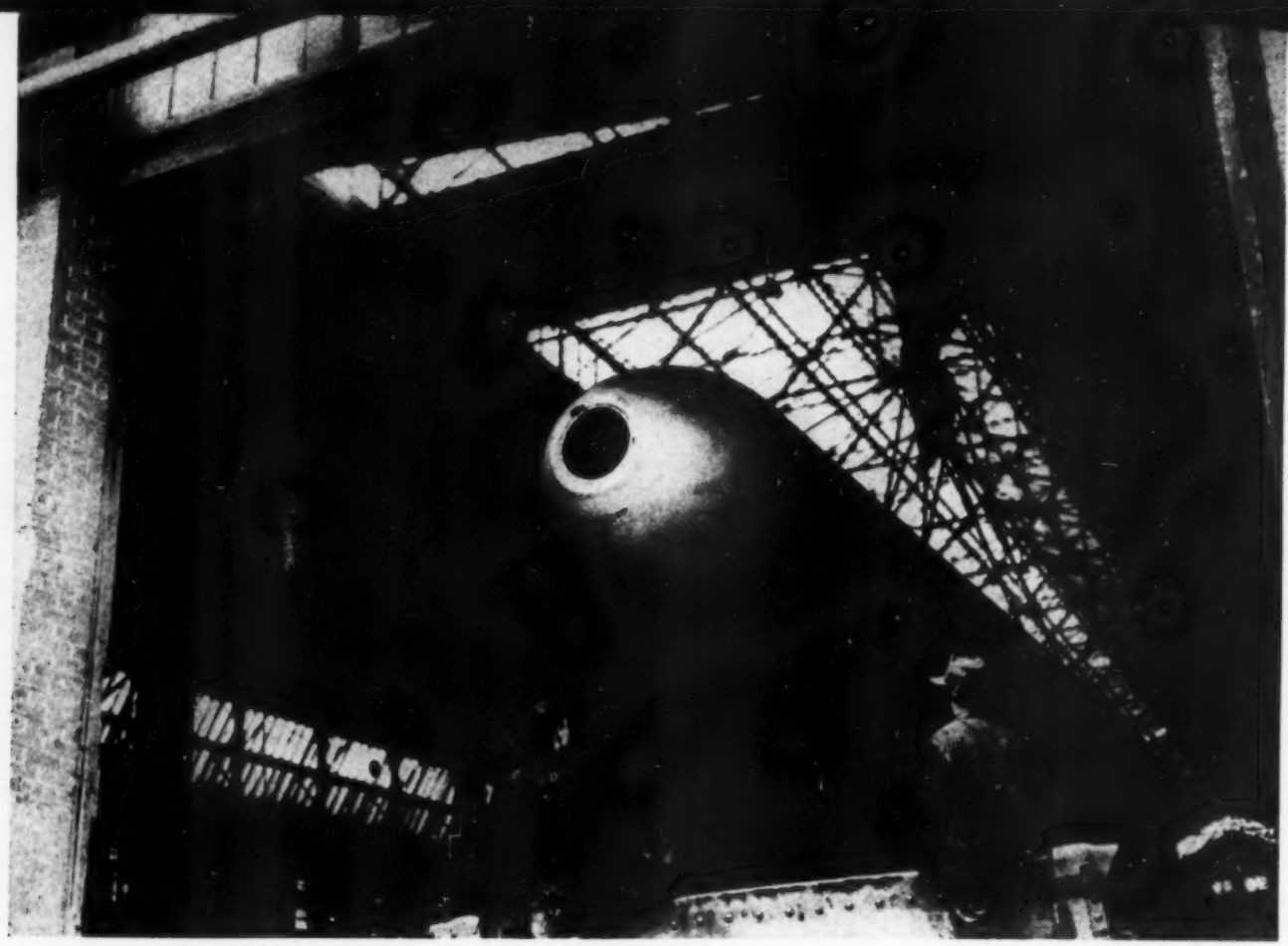
A.I.S.I. Number*	C	Mn	P Max.†	S Max.†	Si†	Ni	Cr	Mo	1946 S.A.E. Number
A 1320	0.18-0.23	1.60-1.90	0.040	0.040	0.20-0.35	.....	.....	.....	1320
A 1330	0.28-0.33	1.60-1.90	0.040	0.040	0.20-0.35	.....	.....	.....	1330
A 1335	0.33-0.38	1.60-1.90	0.040	0.040	0.20-0.35	.....	.....	.....	1335
A 1340	0.38-0.43	1.60-1.90	0.040	0.040	0.20-0.35	.....	.....	.....	1340
A 2317	0.15-0.20	0.40-0.60	0.040	0.040	0.20-0.35	3.25-3.75	.....	.....	{2315 }2317
A 2330	0.28-0.33	0.60-0.80	0.040	0.040	0.20-0.35	3.25-3.75	.....	.....	2330
A 2335	0.33-0.38	0.60-0.80	0.040	0.040	0.20-0.35	3.25-3.75	.....	.....	....
A 2340	0.38-0.43	0.70-0.90	0.040	0.040	0.20-0.35	3.25-3.75	.....	.....	2340
A 2345	0.43-0.48	0.70-0.90	0.040	0.040	0.20-0.35	3.25-3.75	.....	.....	2345
E 2512	0.09-0.14	0.45-0.60	0.025	0.025	0.20-0.35	4.75-5.25	.....	.....	....
A 2515	0.12-0.17	0.40-0.60	0.040	0.040	0.20-0.35	4.75-5.25	.....	.....	2515
E 2517	0.15-0.20	0.45-0.60	0.025	0.025	0.20-0.35	4.75-5.25	.....	.....	....
A 3115	0.13-0.18	0.40-0.60	0.040	0.040	0.20-0.35	1.10-1.40	0.55-0.75	.....	3115
A 3120	0.17-0.22	0.60-0.80	0.040	0.040	0.20-0.35	1.10-1.40	0.55-0.75	.....	3120
A 3130	0.28-0.33	0.60-0.80	0.040	0.040	0.20-0.35	1.10-1.40	0.55-0.75	.....	3130
A 3135	0.33-0.38	0.60-0.80	0.040	0.040	0.20-0.35	1.10-1.40	0.55-0.75	.....	3135
A 3140	0.38-0.43	0.70-0.90	0.040	0.040	0.20-0.35	1.10-1.40	0.55-0.75	.....	3140
A 3141	0.38-0.43	0.70-0.90	0.040	0.040	0.20-0.35	1.10-1.40	0.70-0.90	.....	{X3140 } 3141
A 3145	0.43-0.48	0.70-0.90	0.040	0.040	0.20-0.35	1.10-1.40	0.70-0.90	.....	3145
A 3150	0.48-0.53	0.70-0.90	0.040	0.040	0.20-0.35	1.10-1.40	0.70-0.90	.....	3150
(b)	0.38-0.45	0.40-0.60	0.040	0.040	0.20-0.35	1.65-2.00	0.90-1.20	.....	3240
E 3310	0.08-0.13	0.45-0.60	0.025	0.025	0.20-0.35	3.25-3.75	1.40-1.75	.....	{3310 }3312
E 3316	0.14-0.19	0.45-0.60	0.025	0.025	0.20-0.35	3.25-3.75	1.40-1.75	.....	....
A 4023	0.20-0.25	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4023
A 4024	0.20-0.25	0.70-0.90	0.040	*(a)*	0.20-0.35	.....	.....	0.20-0.30	....
A 4027	0.25-0.30	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4027
A 4028	0.25-0.30	0.70-0.90	0.040	*(a)*	0.20-0.35	.....	.....	0.20-0.30	....
A 4032	0.30-0.35	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4032
A 4037	0.35-0.40	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4037
A 4042	0.40-0.45	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4042
A 4047	0.45-0.50	0.70-0.90	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4047
A 4063	0.60-0.67	0.75-1.00	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4063
A 4068	0.64-0.72	0.75-1.00	0.040	0.040	0.20-0.35	.....	.....	0.20-0.30	4068
(b)	0.17-0.22	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.40-0.60	0.20-0.30	4119
(b)	0.23-0.28	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.40-0.60	0.20-0.30	4125
A 4130	0.28-0.33	0.40-0.60	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	{X4130 } 4130
E 4132	0.30-0.35	0.40-0.60	0.025	0.025	0.20-0.35	.....	0.80-1.10	0.18-0.25	....
E 4135	0.33-0.38	0.70-0.90	0.025	0.025	0.20-0.35	.....	0.80-1.10	0.18-0.25	....
A 4137	0.35-0.40	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	4137
E 4137	0.35-0.40	0.70-0.90	0.025	0.025	0.20-0.35	.....	0.80-1.10	0.18-0.25	....
A 4140	0.38-0.43	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	4140
A 4142	0.40-0.45	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	....
A 4145	0.43-0.48	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	4145
A 4147	0.45-0.50	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	....
A 4150	0.48-0.53	0.75-1.00	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15-0.25	4150
A 4317	0.15-0.20	0.45-0.65	0.040	0.040	0.20-0.35	1.65-2.00	0.40-0.60	0.20-0.30	....
A 4320	0.17-0.22	0.45-0.65	0.040	0.040	0.20-0.35	1.65-2.00	0.40-0.60	0.20-0.30	4320
E 4337	0.35-0.40	0.60-0.80	0.025	0.025	0.20-0.35	1.65-2.00	0.70-0.90	0.20-0.30	....
A 4340	0.38-0.43	0.60-0.80	0.040	0.040	0.20-0.35	1.65-2.00	0.70-0.90	0.20-0.30	{X4340 } 4340
E 4340	0.38-0.43	0.60-0.80	0.025	0.025	0.20-0.35	1.65-2.00	0.70-0.90	0.20-0.30	....
A 4608	0.06-0.11	0.40max.	0.040	0.040	0.25max	1.40-1.75	.....	0.15-0.25	....
A 4615	0.13-0.18	0.45-0.65	0.040	0.040	0.20-0.35	1.65-2.00	.....	0.20-0.30	4615
E 4617	0.15-0.20	0.45-0.65	0.025	0.025	0.20-0.35	1.65-2.00	.....	0.20-0.27	....
A 4620	0.17-0.22	0.45-0.65	0.040	0.040	0.20-0.35	1.65-2.00	.....	0.20-0.30	4620
E 4620	0.17-0.22	0.45-0.65	0.025	0.025	0.20-0.35	1.65-2.00	.....	0.20-0.27	....
A 4621	0.18-0.23	0.70-0.90	0.040	0.040	0.20-0.35	1.65-2.00	.....	0.20-0.30	....
A 4640	0.38-0.43	0.60-0.80	0.040	0.040	0.20-0.35	1.65-2.00	.....	0.20-0.30	4640
E 4640	0.38-0.43	0.60-0.80	0.025	0.025	0.20-0.35	1.65-2.00	.....	0.20-0.27	....
A 4812	0.10-0.15	0.40-0.60	0.040	0.040	0.20-0.35	3.25-3.75	.....	0.20-0.30	....
A 4815	0.13-0.18	0.40-0.60	0.040	0.040	0.20-0.35	3.25-3.75	.....	0.20-0.30	4815
A 4817	0.15-0.20	0.40-0.60	0.040	0.040	0.20-0.35	3.25-3.75	.....	0.20-0.30	....
A 4820	0.18-0.23	0.50-0.70	0.040	0.040	0.20-0.35	3.25-3.75	.....	0.20-0.30	4820
A 5120	0.17-0.22	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.70-0.90	.....	5120
A 5130	0.28-0.33	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.80-1.10	.....	....
A 5140	0.38-0.43	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.70-0.90	.....	5140
A 5145	0.43-0.48	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.70-0.90	.....	....
A 5150	0.48-0.53	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.70-0.90	.....	5150
A 5152	0.48-0.55	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.90-1.20	.....	....
E 52095	0.95-1.10	0.25-0.45	0.025	0.025	0.20-0.35	.....	0.40-0.60	.....	50100
E 52098	0.95-1.10	0.25-0.45	0.025	0.025	0.20-0.35	.....	0.90-1.15	.....	51100
E 52100	0.95-1.10	0.25-0.45	0.025	0.025	0.20-0.35	.....	1.20-1.50	.....	....
E 52101	0.95-1.10	0.25-0.45	0.025	0.025	0.20-0.35	.....	1.30-1.60	.....	52100
A 6120	0.17-0.22	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.70-0.90	0.10min.V	....
A 6145	0.43-0.48	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15min.V	....
A 6150	0.48-0.53	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.15min.V	6150
E 6150	0.48-0.53	0.70-0.90	0.025	0.025	0.20-0.35	.....	0.80-1.10	0.15min.V	....
A 6152	0.48-0.55	0.70-0.90	0.040	0.040	0.20-0.35	.....	0.80-1.10	0.10min.V	....
A 8615 to A 8660; A 8720 to A 8750; A 9255 to A 9262, See Data Sheet No. 17									
E 9310	0.08-0.13	0.45-0.65	0.025	0.025	0.20-0.35	3.00-3.50	1.00-1.40	0.08-0.15	....
E 9315	0.13-0.18	0.45-0.65	0.025	0.025	0.20-0.35	3.00-3.50	1.00-1.40	0.08-0.15	....
E 9317	0.15-0.20	0.45-0.65	0.025	0.025	0.20-0.35	3.00-3.50	1.00-1.40	0.08-0.15	....
A 9437 to A 9445; A 9747 and A 9763; A 9840 to A 9850, See Data Sheet No. 17									

*Prefix A means basic openhearth alloy steel; E means electric furnace steel.

†Lowest standard maximum phosphorus or sulphur content for acid openhearth or acid electric furnace alloy steel is 0.05% each; silicon is 0.15% min.

NOTE *(a)*—Sulphur range: 0.035 to 0.050%.

(b)—Eliminated from A.I.S.I. Standards, as revised July 1, 1946.



Forged Seamless Boiler Drum

Photo by John P. Mudd

mation on the characteristics of ingots. The periscope, illuminated and magnifying, has been the inspection tool. Periscope inspection has long been practiced on turbine or generator rotor forgings, and will no doubt continue to be used for the examination of the hollow interior of large masses of metal.

Nothing has been said so far about hardness testing, although that has continued to maintain its importance for inspection. In fact it is possible that hardness testing is as yet comparatively undeveloped in its field of usefulness. We can possibly couple the microstructure, as revealed by some of our advanced methods, with hardness, and so get sufficient information for the rapid inspection and testing of large quantities of steel. Time and thought given to this subject will develop quicker and better methods. One crying need in the hardness testing field is for still further improvement in accurate, rugged, yet portable equipment. Numerous interesting devices have been used in aircraft factories. The King machine is at present widely used for Brinell hardness testing in the shop, and many jigs and fixtures have been made for standardized Brinell hardness testing on a large scale. However, the Rockwell test finds extensive use on harder materials, and we have as yet no portable Rockwell tester.

As remarked at the outset, the most important objective is uniformity of product. Every customer recognizes the importance of uniformity in steel, but few appreciate the difficulties in attaining it. The raw materials for steelmaking are constantly changing — ores, fuels, and scrap most of all. Added to these are the difficulties of making, intermittently, a product of constant quality. Only by positive control, as we hope we have described it here, can we reasonably hope to attain it.

The Future

When we speak of developing power from gas turbines or by rockets or from the disintegration of atoms, when we speak of airplane speeds of 1500 miles per hr., of guns with twice the muzzle velocity of those in use today, and guided missiles with trajectories 100 miles above the earth's surface, we know that the requirements for the quality of steel will not decrease in the years to come. We think the great contributions to quality control of steel which have come to us from this war period have been the statistical appraisal of the results obtained, together with some few developments in new methods of test. It is possible that with this approach to the subject, we shall go on to ever closer metallurgical control of our product so that when we arrive at testing and inspection we can be practically sure, ahead of time, of the result — certainly a worth-while goal.

ONE OF A SERIES OF STORIES ABOUT ALLOYING METALS . . . WHERE THEY COME FROM AND HOW THEY ARE USED

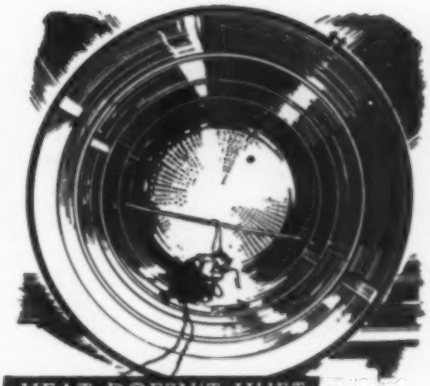
THE STORY OF COLUMBIUM

IN HONOR OF AMERICA

1 In 1801 the British chemist, Hatchett, discovered a new element and named it columbium, in honor of Columbia (America) whence came the mineral specimen he examined. For years this element seemed only an impurity in tantalum, but recently it has gained an important place in metallurgy.

NATIVE CONVEYOR BELT

2 From Nigeria in West Africa come the ores of columbium, one of the scarcer metals. Here, native labor digs and carries the ore by hand to a modern washing plant which separates the ore from the associated tin and tantalum ores. From the concentrates, Electromet makes ferrocolumbium.

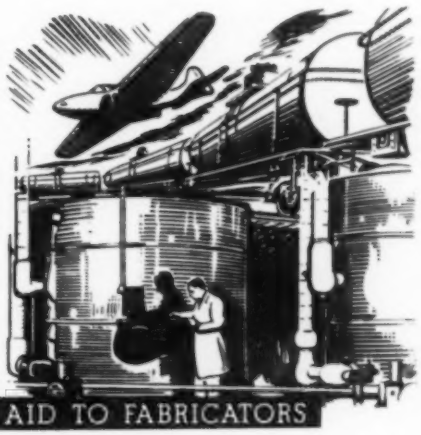


HEAT DOESN'T HURT

3 Columbium preserves corrosion resistance of austenitic chrome-nickel steel when heated to a high temperature. It is unnecessary to anneal welded equipment made of these steels. Fabricators may utilize forgings and castings of a size that could not be properly annealed by commercial methods.

TAKES PUNISHMENT

4 Columbium is essential for improving the creep strength of the super alloys for high-temperature applications such as blades and moving parts of gas turbines and jet propulsion engines. Columbium also reduces air hardening in the straight chromium steels, assuring ductility on cooling.



AID TO FABRICATORS

5 In chrome-nickel stainless steel equipment, welded without annealing, such as large tanks for the chemical, oil, and food industries, columbium preserves corrosion resistance. For high-temperature jobs, such as aircraft manifolds, columbium-bearing chrome-nickel steel is required.

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Fluidity of Acid Openhearth Slag*

TO MAKE POSSIBLE the correlation of slag fluidity data between different shops, a standard fluidity test was developed with a Herty-type fluidity mold. It was found that the length of run of an acid openhearth slag when poured into a tube mold is governed by the ratio of the squares of the bore diameters. Also, the length of run is proportional to the square root of the height of the head. A negligible effect is exerted by the size of the well section at the base of the head, slight eccentricity of the bore, and mold temperatures up to 500° F. The standard fluidimeter adopted has a 3½-in. height of head, a ¾-in. diameter well, a ⅜-in. bore and a tube length of 18 in. (Compare these dimensions with those of the Herty tube viscosimeter: 2-in. height of head, ⅝-in. diameter well, ¼-in. bore and a tube length of 10 in.) Consistent readings are obtained if the mold is clean, the spoon is well slagged, the head is filled to the top, and no time is lost between filling the spoon and pouring the slag.

Data from a large number of heats show that as the slag fluidity decreases progressively during the course of an acid openhearth heat, the SiO_2 content of the slag increases, its FeO content and density decrease, and the metal temperature increases. Because slag fluidity may be used to determine these trends quantitatively, it is a test measure of practical importance. If iron ore or limestone is added to the heat, the slag fluidity in conjunction with carbon tests may be used to indicate when and how much to add as well as the point at which the addition has worked through the slag.

On the basis of such direct relations, a simple control procedure utilizing the fluidity test is described. Since the fluidity test indicates the temperature of a heat, it may be used to determine the point at which the heat is melted. Three plants found that the difference in slag fluidity at meltdown varied from 10 to 11½ in. in the standard mold described above, but, for a given plant and meltdown analysis, the determination was accurate within 1 in. of fluidity. In a given practice, the time when oxidizing additions should be made may be determined by the rates at which the fluidity changes just before and just after the melting period. For example, if this rate is high, the temperature of the bath is rising rapidly, and shortly thereafter ore may be added. A combination of the fluidity test together with carbon analyses serves as an additional guide at this point. After some study, standard charts indicating the amounts of ore and limestone to add may be established for a given practice.

The point at which the heat should be blocked is determined in a given practice not only by the chemical analysis of the heat but also the temperature. The rates of change in carbon and fluidity will aid in predicting when this point will be reached. The temperature at which the heat will tap may be predetermined by increasing or decreasing the fuel during the refining period according to the fluidity readings.

Appendix I discusses the theories of viscosity and the various methods available for the measurement of the absolute (true) viscosity of molten slags (capillary tube, oscillation, falling or rising sphere, and rotating or concentric cylinder methods). These methods are too complex for shop tests. However, Herty previously established a relation between his inclined plane test results and the absolute viscosity. Since there is an excellent correlation between the inclined plane and the standard Acid Openhearth Research Association's mold results, it is possible to indicate a tentative relation between test readings and the absolute viscosity. The true viscosity of acid openhearth finishing slags is probably less than two poises (cgs. unit of absolute viscosity measured in dynes, centimeters and seconds).

Appendix II describes the pycnometer method for measuring the density of acid openhearth slags in the laboratory. It also shows how the slag density of unalloyed heats may be calculated from the composition to an accuracy of 3%, provided the slags do not contain Cr_2O_3.

*Abstracted from "Acid Openhearth Slag Fluidity and Its Significance", by G. R. Fitterer, J. W. Linhart, B. B. Rosenbaum, J. B. Kopec, S. Poch, and W. G. Wilson. Bulletin No. 1 of the Acid Openhearth Research Assoc.

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Steelmaking Practice

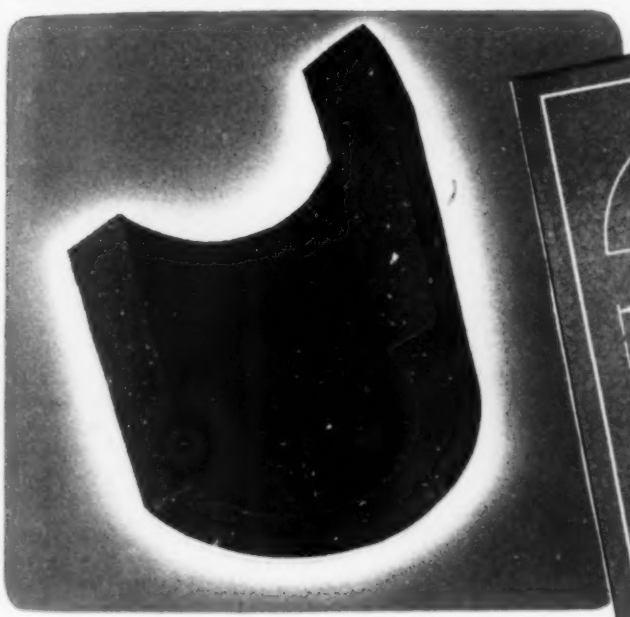
(Continued from page 814)

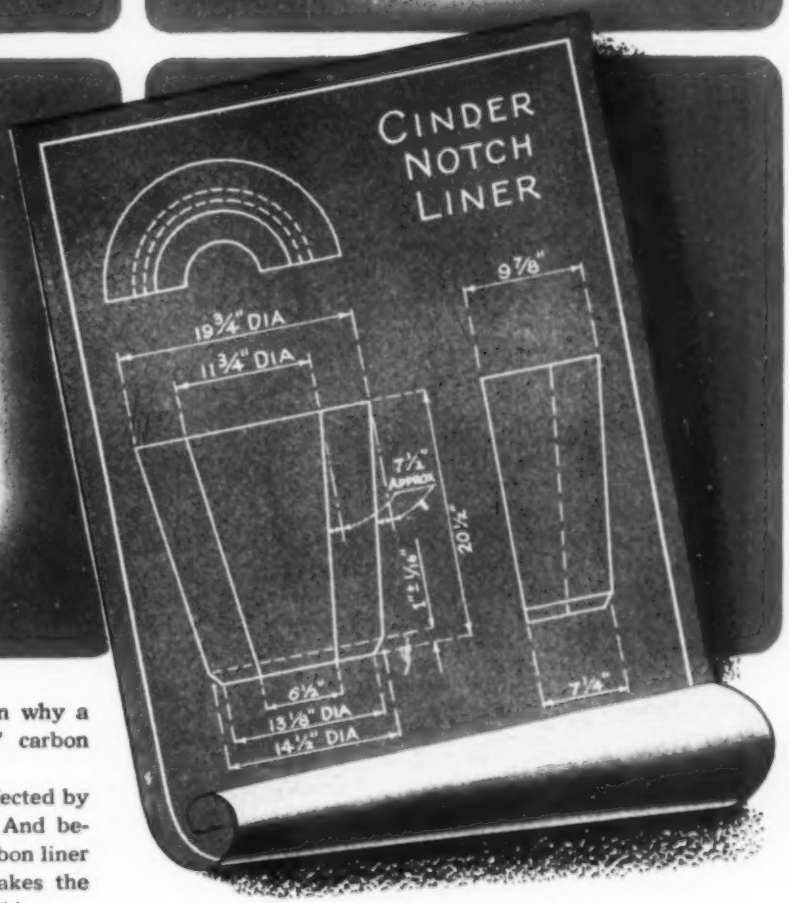
a considerable period, never jeopardized the production of the principal grades of steel.

Manganese — One of the major problems which faced the steel industry during World War I was the shortage of manganese. With this in mind, extensive steps were taken in 1941 to insure an adequate supply of manganese ore and to institute conservation measures which would decrease the consumption of manganese per ton of steel. During the entire course of World War II, the steel industry was never short of manganese due to the success of these two steps. Conservation included a reduction in manganese content of many grades of steel (brought about by specification writing bodies), a drive in the steel industry to use the least possible amount of manganese consistent with the qualities desired in wartime steel, and the adoption of openhearth practices which would lead to the maximum utilization of manganese in raw materials and the maximum possible efficiency of added manganese. The over-all result of all these steps was to bring about a reduction of about 20% in the amount of manganese used per ton of steel, thus correspondingly increasing the reserves of manganese ores. Figure 7 (page 814) shows the progress of manganese conservation from early 1940 to mid-1942 in two plants where all of the above conservation measures were effective.

Alloys Recovered from Scrap — It is now history that there was a time when we were faced with shortages of nickel, chromium and molybdenum. Steps taken to avert these shortages were: First, changes in the types of steel which were produced — and there were at least three major changes in this regard; and second, a drive by the industry to recover more alloy from scrap than had been current practice prior to the war. This was truly an industry-wide effort and as a result the recovery of nickel from scrap increased more than 10%, the recovery of molybdenum about 12%, and the recovery of chromium about 5%. This was a major contribution toward the conservation of our supplies of strategic elements and, in no small measure, contributed to the ability of the industry to produce the required quantities of alloy steel for the war effort.

How Long will a CARBON CINDER NOTCH LINER Last?





IF INSTALLED properly, there is no reason why a cinder notch liner made of "National" carbon should not last for *many years!* Why?

Because "National" carbon is totally unaffected by corrosive slag attack or by thermal shock. And because, being made of only two pieces, the carbon liner has only two joints! (This feature also makes the carbon cinder notch quick and easy to install.)

Send for more details! Engineers at National Carbon are ready to assist in the design of a carbon cinder notch for your particular furnaces. Write to Dept. M.P.

• • •

Entirely unaffected by corrosive slags.
Unharmed by thermal shock.
Easy to install—fewer joints.

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(Electric Furnace or Openhearth Bars, Billets or Blooms)

S.A.E. or A.I.S.I. Designation	Chemical Composition★					
	C	Mn	Si	Ni	Cr	Mo
2512 H	0.08/0.15	0.35/0.65	0.20/0.35	4.70/5.30	—	—
2515 H	0.11/0.18	0.35/0.65	0.20/0.35	4.70/5.30	—	—
2517 H	0.16/0.21	0.35/0.65	0.20/0.35	4.70/5.30	—	—
3310 H	0.07/0.14	0.35/0.65	0.20/0.35	3.20/3.80	1.35/1.75	—
3316 H	0.13/0.20	0.35/0.65	0.20/0.35	3.20/3.80	1.35/1.75	—
4130 H	0.27/0.34	0.35/0.65	0.20/0.35	—	0.80/1.15	0.15/0.25
4132 H	0.30/0.37	0.35/0.65	0.20/0.35	—	0.80/1.15	0.15/0.25
4135 H	0.32/0.39	0.60/0.95	0.20/0.35	—	0.80/1.15	0.15/0.25
4137 H	0.35/0.43	0.60/0.95	0.20/0.35	—	0.80/1.15	0.15/0.25
4140 H	0.37/0.45	0.70/1.05	0.20/0.35	—	0.80/1.15	0.15/0.25
4142 H	0.40/0.48	0.70/1.05	0.20/0.35	—	0.80/1.15	0.15/0.25
4145 H	0.42/0.50	0.70/1.05	0.20/0.35	—	0.80/1.15	0.15/0.25
4147 H	0.44/0.52	0.70/1.05	0.20/0.35	—	0.80/1.15	0.15/0.25
4150 H	0.46/0.54	0.70/1.05	0.20/0.35	—	0.80/1.15	0.15/0.25
4317 H	0.14/0.21	0.40/0.70	0.20/0.35	1.50/2.00	0.35/0.65	0.20/0.30
4320 H	0.16/0.23	0.40/0.70	0.20/0.35	1.50/2.00	0.35/0.65	0.20/0.30
4340 H	0.37/0.45	0.60/0.95	0.20/0.35	1.50/2.00	0.65/0.95	0.20/0.30
4620 H	0.17/0.24	0.40/0.70	0.20/0.35	1.50/2.00	—	0.20/0.30
4640 H	0.37/0.45	0.55/0.85	0.20/0.35	1.50/2.00	—	0.20/0.30
4815 H	0.12/0.19	0.35/0.65	0.20/0.35	3.20/3.80	—	0.20/0.30
4820 H	0.17/0.24	0.45/0.75	0.20/0.35	3.20/3.80	—	0.20/0.30
8620 H	0.17/0.24	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8622 H	0.20/0.27	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8625 H	0.22/0.29	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8627 H	0.25/0.32	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8630 H	0.27/0.34	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8632 H	0.30/0.37	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8635 H	0.32/0.39	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8637 H	0.35/0.43	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8640 H	0.37/0.45	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8642 H	0.40/0.48	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8645 H	0.42/0.50	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8647 H	0.44/0.52	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8650 H	0.46/0.54	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8720 H	0.17/0.24	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8722 H	0.20/0.27	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8725 H	0.22/0.29	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8727 H	0.25/0.32	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8730 H	0.27/0.34	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8732 H	0.30/0.37	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8735 H	0.32/0.39	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8737 H	0.35/0.43	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8740 H	0.37/0.45	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8742 H	0.40/0.48	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8745 H	0.42/0.50	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8747 H	0.44/0.52	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8750 H	0.46/0.54	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
NE 9420 H	0.17/0.24	0.80/1.15	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9422 H	0.20/0.27	0.80/1.15	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9425 H	0.22/0.29	0.80/1.15	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9427 H	0.25/0.32	0.80/1.15	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9430 H	0.27/0.34	0.85/1.25	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9432 H	0.30/0.37	0.85/1.25	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9435 H	0.32/0.39	0.85/1.25	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9437 H	0.35/0.43	0.85/1.25	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9440 H	0.37/0.45	0.85/1.25	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9442 H	0.40/0.48	0.95/1.35	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9445 H	0.42/0.50	0.95/1.35	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9447 H	0.44/0.52	1.15/1.55	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9450 H	0.46/0.54	1.15/1.55	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15

NOTE — NE denotes National Emergency Standard Steel.

General Notes

These compositions apply to steels produced to tentative hardenability bands (Data Sheets 19 to 24), determined by the standard end-quench on 1-in. round bars (Data Sheet 55), and to steels manufactured to "fine-grained steel practice".

Size and Shape Limits: 100 sq. in. in cross-sectional area, or 18 in. in width, or 7000 lb. in weight.

Hardenability of "H" steels may be specified in several ways: *(a)* Max. and min. distances on Jominy bar for any desired hardness; *(b)* Max. and min. hardness at any specified distance; *(c)* Two max. hardness values at two desired distances; *(d)* Two min. hardness values at two desired distances; *(e)* Any point on min. hardenability curve plus any point on max. curve. In addition to any of the above, the hardness limits at 1/16 in. may be specified.

★Permissible Chemical Variations

Phosphorus and sulphur in openhearth steel to be 0.040% max. each.

Phosphorus and sulphur in electric furnace steel to be 0.025% max. each.

Small quantities of certain elements may be found in alloy steel which are not specified or required. These elements are to be considered as incidental and acceptable to the following maximum amounts: Copper 0.35%, nickel 0.25%, chromium 0.20%, molybdenum 0.06%.

The chemical ranges and limits shown are subject to the standard permissible variations for check analysis over the maximum limit or under the minimum limit. These permissible variations are: 0.01 for all ranges of carbon; 0.03 for manganese up to and including 0.90%, and 0.04 for over 0.90 to 1.55% inclusive; 0.005 for either phosphorus or sulphur; 0.02 for silicon; 0.03 for nickel up to and including 1.00%, 0.05 for nickel over 1.00 up to and including 2.00%, and 0.07 over 2.00 up to and including 5.30%; 0.03 for chromium up to 0.90% inclusive, and 0.05 for chromium over 0.90 to 1.75% inclusive; 0.01 for molybdenum up to 0.20% inclusive, 0.02 for molybdenum over 0.20 to 0.30% inclusive.

Quality Conditions — All conditions and quality features, except as detailed above, shall be in accordance with the regulation shown in the American Iron and Steel Institute's "Steel Products Manual", Section 10 on Alloy Steels.

SPECIFY VANCORAM FERRO VANADIUM

FOR HIGHEST QUALITY ALLOY STEELS

Whether you produce wrought constructional steels, alloy steel castings, high speed tool steels or special-purpose steels, there is a grade of Vancoram Ferro Vanadium designed to meet your requirements. Our modern quality-control methods result in a higher quality product of dependable uniformity—thus assuring the steelmaker closer control and unexcelled microstructure and physical properties.

To cover the more common steelmaking needs we supply:

	Grade A (Open Hearth)	Grade B (Crucible)	Grade C (Primos)
Vanadium	35 to 40%	35 to 45%	35 to 45%
Silicon	12% max.	3.5% max.	1.25% max.
Carbon	3.5% max.	0.5% max.	0.20% max.

Special grades, containing up to 80% Vanadium, and Vanadium Metals, containing 90% and 95% Vanadium, are also available.

All grades are carried in stock and can be supplied in large lumps, or crushed or ground to any desired size. Our metallurgists will gladly discuss the application of Vancoram Ferro Vanadium in terms of your requirements.

MAKERS OF FERRO ALLOYS — VANCORAM — CHEMICALS AND METALS

VANADIUM CORPORATION OF AMERICA

420 LEXINGTON AVENUE, NEW YORK 17, N. Y. • DETROIT • CHICAGO • CLEVELAND • PITTSBURGH

National Emergency Alloy Steels*

Openhearth Alloy and Electric Furnace Alloy Steels; Blooms, Billets, Slabs, Bars and Hot Rolled Strip. *Revised July 29, 1946*

Adopted	Aban-doned	Desig-nation	C	Mn	Si (a)	Ni	Cr	Mo	Hardenability (b) Low	Hardenability (b) High
Carbon-Manganese Steels										
8/17/42	1/ 2/45	NE1330	0.28-0.33	1.60-1.90	0.20-0.35	(c)	(d)	(e)	1.53	4.24
8/17/42	1/ 2/45	NE1335	0.33-0.38	1.60-1.90	0.20-0.35	(c)	(d)	(e)	1.67	4.54
8/17/42	1/ 2/45	NE1340	0.38-0.43	1.60-1.90	0.20-0.35	(c)	(d)	(e)	1.80	4.79
8/17/42	1/ 2/45	NE1345	0.43-0.48	1.60-1.90	0.20-0.35	(c)	(d)	(e)	1.91	5.10
8/17/42	1/ 2/45	NE1350	0.48-0.53	1.60-1.90	0.20-0.35	(c)	(d)	(e)	2.02	5.39
Carbon-Chromium Steels (f)										
8/17/42	1/ 2/45	NE52100 C	0.95-1.10	0.25-0.45	0.20-0.35	0.35max.	0.40-0.60	0.08max.	1.19	4.0
8/17/42	1/ 2/45	NE52100 B	0.95-1.10	0.25-0.45	0.20-0.35	0.35max.	0.90-1.15	0.08max.	1.74	6.0 (g)
8/17/42	1/ 2/45	NE52100 A	0.95-1.10	0.25-0.45	0.20-0.35	0.35max.	1.30-1.60	0.08max.	2.40	8.7 (g)
Manganese-Molybdenum Steels										
8/17/42	8/15/43	NE8020	0.18-0.23	1.00-1.30	0.20-0.35			0.10-0.20		
8/17/42	12/17/42	NE8022	0.20-0.25	1.00-1.30	0.20-0.35			0.10-0.20		
1/21/42	8/17/42	NE8024	0.22-0.28	1.00-1.30	0.20-0.35			0.10-0.20		
1/21/42	8/17/42	NE8124	0.22-0.28	1.30-1.60	0.20-0.35			0.25-0.35		
1/21/42	8/17/42	NE8233	0.30-0.36	1.30-1.60	0.20-0.35			0.10-0.20		
1/21/42	8/17/42	NE8245	0.42-0.49	1.30-1.60	0.20-0.35			0.10-0.20		
1/21/42	12/17/42	NE8339	0.35-0.42	1.30-1.60	0.20-0.35			0.20-0.30		
1/21/42	8/15/43	NE8442	0.40-0.45	1.30-1.60	0.20-0.35			0.30-0.40		
1/21/42	8/17/42	NE8447	0.43-0.50	1.30-1.60	0.20-0.35			0.30-0.40		
1/21/42	8/17/42	NE8547	0.43-0.50	1.30-1.60	0.20-0.35			0.40-0.60		
Nickel-Chromium-Molybdenum Steels ("Standard" Steels, also taking the prefix A)										
5/26/44	7/ 1/46	NE8612	0.10-0.15	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	1.07	3.68
8/17/42	5/26/44	NE8613	0.12-0.17	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25		
8/17/42		NE8615	0.13-0.18	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	1.34	4.02
8/17/42		NE8617	0.15-0.20	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	1.43	4.25
1/21/42		NE8620	0.18-0.23	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	1.52	4.47
5/26/44		NE8622	0.20-0.25	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	1.65	4.77
5/26/44		NE8625	0.23-0.28	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	1.72	4.96
5/26/44		NE8627	0.25-0.30	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	1.84	5.23
1/21/42		NE8630	0.28-0.33	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	1.91	5.47
5/26/44		NE8632	0.30-0.35	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	2.00	5.64
12/17/42		NE8635	0.33-0.38	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	2.22	6.35
12/17/42		NE8637	0.35-0.40	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	2.28	6.50
12/17/42		NE8640	0.38-0.43	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	2.38	6.75
7/29/46		NE8641(m)	0.38-0.43	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	2.38	6.75
12/17/42		NE8642	0.40-0.45	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	2.44	6.90
12/17/42		NE8645	0.43-0.48	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	2.53	7.15
5/26/44		NE8647	0.45-0.50	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	2.59	7.35
12/17/42		NE8650	0.48-0.53	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	2.67	7.55
7/ 1/46		NE 8655	0.50-0.60	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	2.72	8.03
7/ 1/46		NE 8660	0.55-0.65	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.15-0.25	2.85	8.37
8/26/44	7/ 1/46	NE8712	0.10-0.15	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	1.30	4.01
5/26/44	7/ 1/46	NE8715	0.13-0.18	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	1.48	4.39
5/26/44	7/ 1/46	NE8717	0.15-0.20	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	1.58	4.63
5/26/44		NE8720	0.18-0.23	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	1.72	4.98
5/26/44	7/ 1/46	NE8722	0.20-0.25	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	1.82	5.20
1/21/42	8/17/42	NE8724	0.22-0.28	0.70-0.90	0.20-0.35	0.40-0.60	0.40-0.60	0.20-0.30		
5/26/44	7/ 1/46	NE8725	0.23-0.28	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	1.95	5.50
5/26/44	7/ 1/46	NE8727	0.25-0.30	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	2.03	5.70
5/26/44	7/ 1/46	NE8730	0.28-0.33	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	2.14	5.95
5/26/44	7/ 1/46	NE8732	0.30-0.35	0.70-0.90	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	2.22	6.15
5/26/44		NE8735	0.33-0.38	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	2.44	6.90
5/26/44	7/ 1/46	NE8737	0.35-0.40	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	2.52	7.05
1/21/42	12/17/42	NE8739	0.35-0.42	0.75-1.00	0.20-0.35	0.40-0.60	0.40-0.60	0.20-0.30		
8/26/44		NE8740	0.38-0.43	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	2.62	7.35
5/26/44		NE8742	0.40-0.45	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	2.70	7.50
1/21/42	12/17/42	NE8744	0.40-0.47	0.75-1.00	0.20-0.35	0.40-0.60	0.40-0.60	0.20-0.30		
5/26/44		NE8745	0.43-0.48	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	2.79	7.75
5/26/44		NE8747	0.45-0.50	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	2.86	7.95
1/21/42	12/17/42	NE8749	0.45-0.52	0.75-1.00	0.20-0.35	0.40-0.60	0.40-0.60	0.20-0.30		
5/26/44		NE8750	0.48-0.53	0.75-1.00	0.20-0.35	0.40-0.70	0.40-0.60	0.20-0.30	2.95	8.20
1/21/42	8/17/42	NE8817	0.15-0.20	0.70-0.95	0.20-0.35	0.40-0.60	0.40-0.60	0.30-0.40		
1/21/42	12/17/42	NE8949	0.45-0.52	1.00-1.30	0.20-0.35	0.40-0.60	0.40-0.60	0.30-0.40		

Adopted	Aban-doned	Desig-nation	C	Mn	Si (a)	Ni	Cr	Mo	Hardenability (b) Low	Hardenability (b) High
Silicon-Manganese and Silicon-Manganese-Chromium Steels										
8/17/42		NE9255	0.50-0.60	0.70-0.95	1.80-2.20	(c)	(d)	(e)	2.20	6.60
8/17/42		NE9260	0.55-0.65	0.70-1.00	1.80-2.20	(c)	(d)	(e)	2.34	7.15
8/15/43		NE9261	0.55-0.65	0.75-1.00	1.80-2.20	(c)	0.10-0.25	(e)	2.60	9.20
8/17/42		NE9262	0.55-0.65	0.75-1.00	1.80-2.20	(c)	0.25-0.40	(e)	3.36	10.5
Manganese-Nickel-Chromium-Molybdenum Steels (h)										
8/17/42	7/ 1/46	NE9415	0.13-0.18	0.80-1.10	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	1.15	3.52
5/26/44	7/ 1/46	NE9417	0.15-0.20	0.80-1.10	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	1.23	3.70
8/17/42	7/ 1/46	NE9420	0.18-0.23	0.80-1.10	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	1.34	3.99
8/17/42	7/ 1/46	NE9422	0.20-0.25	0.80-1.10	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	1.42	4.17
8/15/43	7/ 1/46	NE9425	0.23-0.28	0.80-1.10	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	1.66	4.72
5/26/44	7/ 1/46	NE9427	0.25-0.30	0.80-1.10	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	1.72	4.89
8/17/42	7/ 1/46	NE9430	0.28-0.33	0.90-1.20	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	1.81	5.10
5/26/44	7/ 1/46	NE9432	0.30-0.35	0.90-1.20	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	1.88	5.25
8/17/42	7/ 1/46	NE9435	0.33-0.38	0.90-1.20	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	1.98	5.45
8/17/42		NE9437	0.35-0.40	0.90-1.20	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	2.03	5.60
8/17/42		NE9440	0.38-0.43	0.90-1.20	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	2.12	5.80
8/17/42		NE9442	0.40-0.45	1.00-1.30	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	2.36	6.50
8/17/42		NE9445	0.43-0.48	1.00-1.30	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	2.45	6.75
5/26/44	7/ 1/46	NE9447	0.45-0.50	1.20-1.50	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	2.90	8.05
8/17/42	7/ 1/46	NE9450	0.48-0.53	1.20-1.50	0.20-0.35	0.30-0.60	0.30-0.50	0.08-0.15	2.99	8.30
Manganese-Silicon-Nickel-Chromium-Molybdenum Steels										
8/17/42	5/26/44	NE9537 (i)	0.35-0.40	1.20-1.50	0.40-0.60	0.40-0.70	0.40-0.60	0.15-0.25		
8/17/42	5/26/44	NE9540 (i)	0.38-0.43	1.20-1.50	0.40-0.60	0.40-0.70	0.40-0.60	0.15-0.25		
8/17/42	5/26/44	NE9542 (i)	0.40-0.45	1.20-1.50	0.40-0.60	0.40-0.70	0.40-0.60	0.15-0.25		
8/15/43	5/26/44	NE9545 (i)	0.43-0.48	1.20-1.50	0.40-0.60	0.40-0.70	0.40-0.60	0.15-0.25		
8/17/42	5/26/44	NE9550 (i)	0.48-0.53	1.20-1.50	0.40-0.60	0.40-0.70	0.40-0.60	0.15-0.25		
Manganese-Silicon-Chromium Steels										
8/17/42	8/15/43	NE9630	0.28-0.33	1.20-1.50	0.40-0.60		0.40-0.60			
8/17/42	8/15/43	NE9635	0.33-0.38	1.20-1.50	0.40-0.60		0.40-0.60			
8/17/42	8/15/43	NE9637	0.35-0.40	1.20-1.50	0.40-0.60		0.40-0.60			
8/17/42	8/15/43	NE9640	0.38-0.43	1.20-1.50	0.40-0.60		0.40-0.60			
8/17/42	8/15/43	NE9642	0.40-0.45	1.30-1.60	0.40-0.60		0.40-0.60			
8/17/42	8/15/43	NE9645	0.43-0.48	1.30-1.60	0.40-0.60		0.40-0.60			
8/17/42	8/15/43	NE9650	0.48-0.53	1.30-1.60	0.40-0.60		0.40-0.60			
Nickel-Molybdenum Steels (j)										
5/26/44	7/ 1/46	NE9722	0.20-0.25	0.50-0.80	0.20-0.35	0.40-0.70	0.10-0.25	0.15-0.25	0.90	3.31
5/26/44	7/ 1/46	NE9727	0.25-0.30	0.50-0.80	0.20-0.35	0.40-0.70	0.10-0.25	0.15-0.25	1.00	3.63
5/26/44	7/ 1/46	NE9732	0.30-0.35	0.50-0.80	0.20-0.35	0.40-0.70	0.10-0.25	0.15-0.25	1.09	3.92
5/26/44	7/ 1/46	NE9737	0.35-0.40	0.50-0.80	0.20-0.35	0.40-0.70	0.10-0.25	0.15-0.25	1.18	4.16
5/26/44	7/ 1/46	NE9742	0.40-0.45	0.50-0.80	0.20-0.35	0.40-0.70	0.10-0.25	0.15-0.25	1.27	4.42
5/26/44	7/ 1/46	NE9745	0.43-0.48	0.50-0.80	0.20-0.35	0.40-0.70	0.10-0.25	0.15-0.25	1.31	4.57
5/26/44		NE9747	0.45-0.50	0.50-0.80	0.20-0.35	0.40-0.70	0.10-0.25	0.15-0.25	1.34	4.68
5/26/44	7/ 1/46	NE9750	0.48-0.53	0.50-0.80	0.20-0.35	0.40-0.70	0.10-0.25	0.15-0.25	1.39	4.84
5/26/44		NE9763	0.60-0.67	0.50-0.80	0.20-0.35	0.40-0.70	0.10-0.25	0.15-0.25	1.55	5.05
5/26/44	7/ 1/46	NE9768	0.64-0.72	0.50-0.80	0.20-0.35	0.40-0.70	0.10-0.25	0.15-0.25	1.60	4.65
Nickel-Chromium-Molybdenum Steels (k)										
5/26/44	7/ 1/46	NE9830 (i)	0.28-0.33	0.70-0.90	0.20-0.35	0.85-1.15	0.70-0.90	0.20-0.30	2.91	8.45
5/26/44	7/ 1/46	NE9832 (i)	0.30-0.35	0.70-0.90	0.20-0.35	0.85-1.15	0.70-0.90	0.20-0.30	3.02	8.75
5/26/44	7/ 1/46	NE9835 (i)	0.33-0.38	0.70-0.90	0.20-0.35	0.85-1.15	0.70-0.90	0.20-0.30	3.18	9.05
6/26/44	7/ 1/46	NE9837 (i)	0.35-0.40	0.70-0.90	0.20-0.35	0.85-1.15	0.70-0.90	0.20-0.30	3.26	9.30
5/26/44		NE9840 (i)	0.38-0.43	0.70-0.90	0.20-0.35	0.85-1.15	0.70-0.90	0.20-0.30	3.41	9.65
5/26/44	7/ 1/46	NE9842 (i)	0.40-0.45	0.70-0.90	0.20-0.35	0.85-1.15	0.70-0.90	0.20-0.30	3.50	9.85
5/26/44		NE9845 (i)	0.43-0.48	0.70-0.90	0.20-0.35	0.85-1.15	0.70-0.90	0.20-0.30	3.62	10.2
5/26/44	7/ 1/46	NE9847 (i)	0.45-0.50	0.70-0.90	0.20-0.35	0.85-1.15	0.70-0.90	0.20-0.30	3.70	10.5
5/26/44		NE9850 (i)	0.48-0.53	0.70-0.90	0.20-0.35	0.85-1.15	0.70-0.90	0.20-0.30	3.83	10.8
Triple Steels for Carburizing (l)										
5/26/44	7/ 1/46	NE9912	0.10-0.15	0.50-0.70	0.20-0.35	1.00-1.30	0.40-0.60	0.20-0.30	1.23	3.92
5/26/44	7/ 1/46	NE9915	0.13-0.18	0.50-0.70	0.20-0.35	1.00-1.30	0.40-0.60	0.20-0.30	1.41	4.29
5/26/44	7/ 1/46	NE9917	0.15-0.20	0.50-0.70	0.20-0.35	1.00-1.30	0.40-0.60	0.20-0.30	1.50	4.52
5/26/44	7/ 1/46	NE9920	0.18-0.23	0.50-0.70	0.20-0.35	1.00-1.30	0.40-0.60	0.20-0.30	1.64	4.86
5/26/44	7/ 1/46	NE9922	0.20-0.25	0.50-0.70	0.20-0.35	1.00-1.30	0.40-0.60	0.20-0.30	1.74	5.10
5/26/44	7/ 1/46	NE9925	0.23-0.28	0.50-0.70	0.20-0.35	1.00-1.30	0.40-0.60	0.20-0.30	1.86	5.40

Notes

*All National Emergency Steels are subject to the conditions concerning chemical ranges and phosphorus and sulphur maxima as outlined for standard alloy steels on pages 19 and 20 inclusive in the latest revision of American Iron & Steel Institute's Steel Product Manual No. 10, entitled "Alloy Steels", and to the standard permissible variations from specified ranges as listed on page 27 of that Manual. Large sections are subject to modifications of carbon content only to a range of 0.10 (10 points); see page 24 of Manual No. 10.

Phosphorus and Sulphur Limits: When basic electric furnace steel is specified, phosphorus and sulphur limits are to be 0.025% max. each; for basic openhearth steel 0.040% max. each; for acid openhearth or electric steel 0.050% max. each. (These elements not used in computing hardenability.)

(a) For basic steel. Lowest minimum silicon limit to be specified for acid steel is 0.15%.

(b) Not part of the specifications. Computed by Grossmann's methods as outlined in "Metal Progress" Data Sheet No. 51, as modified by Crafts and Lamont, for grain sizes 8 and 5 (low and high side respectively).

(c) Supposedly none. Hardenability computations assume 0.10-0.25.

(d) Ditto. Assumed 0.05-0.10.

(e) Ditto. Assumed 0.00-0.08.

(f) NE52100 steels are for ball and roller bearings. Copper is limited to 0.25% max. in all analyses, and limits for inclusions are to be according to A.S.T.M. specification E45-a.

(g) Doubtful, from unknown effect of undissolved carbides.

(h) NE9400 series, as established Aug. 17, 1942, had high-silicon (0.40-0.60%), and low nickel and chromium (0.20 to 0.40% each). Silicon, nickel and chromium were dropped to their present ranges on Aug. 15, 1943. Also take prefix A.

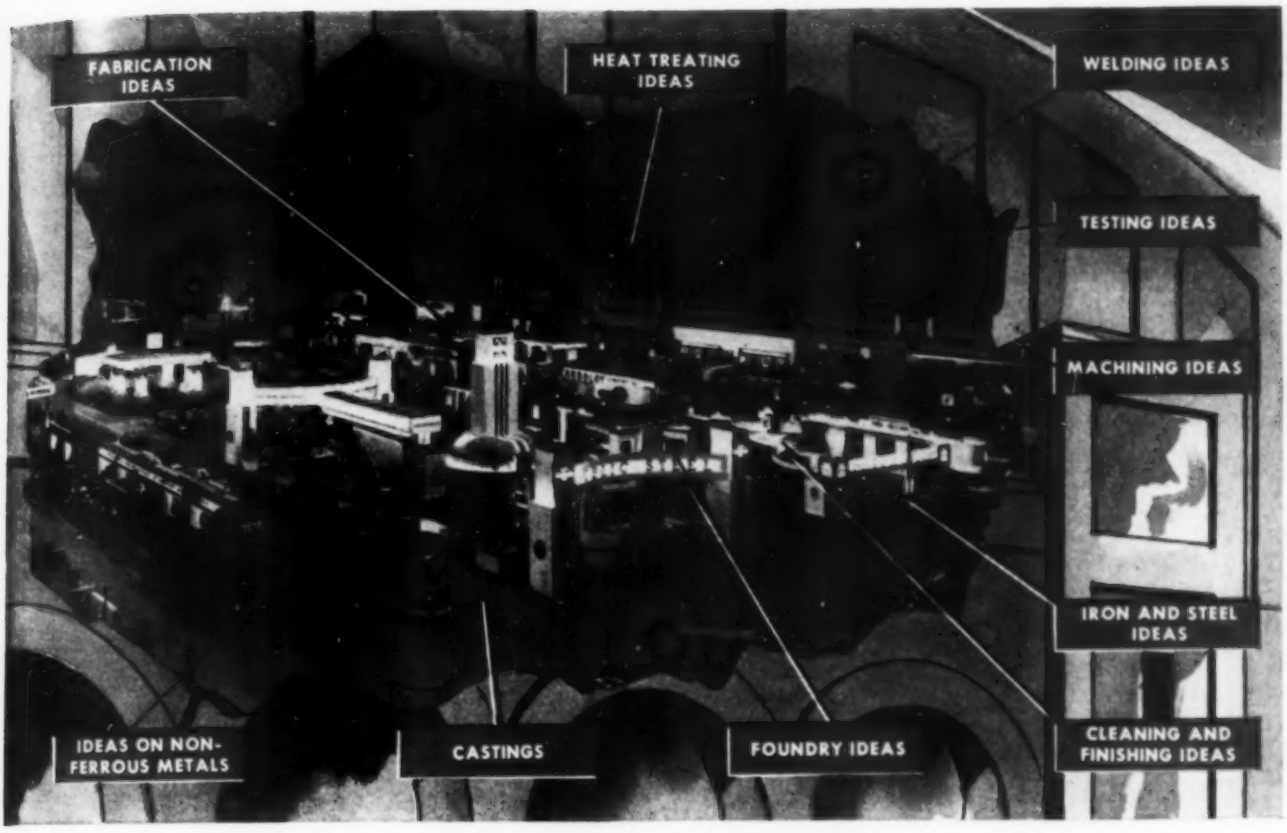
(i) For large sections only.

(j) Hardenability similar to A4000 series.

(k) NE9800 series includes deep hardening steels with hardenability between NE8700 and A4300 series.

(l) NE9900 series includes higher nickel carburizing steels with similar hardenability to NE8700.

(m) Sulphur 0.040 to 0.060%.



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Standard Stainless Steels

Cast and Wrought

Wrought Stainless Steels *(a)*

(American Iron and Steel Institute Designations; May 1946)

Type No.	Carbon	Chromium	Nickel	Other Elements *(b)*
301	0.08-0.15	16.0-18.0	6.0- 8.0	
302 *(c)*	0.08-0.15	17.0-19.0	8.0-10.0	
302-B	0.08-0.15	17.0-19.0	8.0-10.0	Si 2.00-3.00
303 *(d)*	0.15 max.	17.0-19.0	8.0-10.0	P or S or Se 0.07 min.; Mo or Zr 0.60 max.
304 *(e)*	0.08 max.	18.0-20.0	8.0-11.0	
308	0.08 max.	19.0-21.0	10.0-12.0	
309	0.20 max.	22.0-24.0	12.0-15.0	
310	0.25 max.	24.0-26.0	19.0-22.0	Si 1.50 max.
316 *(f)*	0.10 max.	16.0-18.0	10.0-14.0	Mo 1.75-2.75
321 *(g)*	0.10 max.	17.0-19.0	8.0-11.0	Ti is 5 × C (min.)
347 *(g)*	0.10 max.	17.0-19.0	9.0-12.0	Cb is 10 × C (min.)
403	0.15 max.	11.5-13.0		Turbine quality; Si 0.50 max.
405	0.08 max.	11.5-13.5		Al 0.10-0.30
406	0.15 max.	12.0-14.0		Al 3.50-4.50
410 *(h)*	0.15 max.	11.5-13.5		
414 *(i)*	0.15 max.	11.5-13.5	1.25-2.50	
416 *(j)*	0.15 max.	12.0-14.0		P or S or Se 0.07 min.; Mn 1.25 max.; Mo or Zr 0.60 max.
420 *(k)*	Over 0.15	12.0-14.0		
430 *(l)*	0.12 max.	14.0-18.0		
430-F	0.12 max.	14.0-18.0		P or S or Se 0.07 min.; Mo or Zr 0.60 max.
431	0.20 max.	15.0-17.0	1.25-2.50	
440-A	0.60-0.75	16.0-18.0		Mo 0.75 max.
440-B	0.75-0.95	16.0-18.0		Mo 0.75 max.
440-C	0.95-1.20	16.0-18.0		Mo 0.75 max.
442	0.25 max.	18.0-23.0		
443	0.20 max.	18.0-23.0		Cu 0.90-1.25
446	0.35 max.	23.0-27.0		N_2 0.25 max.
501	Over 0.10	4.0- 6.0		
502	0.10 max.	4.0- 6.0		

(a) All composition ranges are based on ladle analysis. For standard permissible variations from specified chemical ranges or limits for check analysis, see pages 10 to 13, Section 24, A.I.S.I. Steel Products Manual.

(b) Manganese — 2.00 max. in all 300 types, 1.00 max. in all 400 and 500 types except 416. Silicon — 1.00 max. in all types except 302-B, 310 and 403. Phosphorus — 0.040 max. in all types except 303, 416 and 430-F. Sulphur — 0.040 max. in all types except 303, 416 and 430-F.

(c) S.A.E. 30915.

(d) S.A.E. 30615 (Type 1) is equivalent to high sulphur 303; S.A.E. 30615 (Type 2) is equivalent to high selenium 303.

(e) S.A.E. 30905.

(f) S.A.E. 30805.

(g) S.A.E. 30705.

(h) S.A.E. 51210.

(i) S.A.E. 51310.

(j) S.A.E. X51410.

(k) S.A.E. 51335.

(l) S.A.E. 51710.

Cast Stainless Steels *(m)*

(Alloy Casting Institute Designations; September 1946)

Type No. *(n)*	Carbon	Chromium	Nickel	Other Elements
CA-15	0.15 max.	11.0-14.0	1.0 max.	
CA-40	0.20-0.40	11.0-14.0	1.0 max.	
CB-30	0.30 max.	18.0-22.0	2.0 max.	
CC-50	0.50 max.	26.0-30.0	4.0 max.	
CE-30	0.30 max.	26.0-30.0	8.0-11.0	
CF-7	0.07 max.	18.0-20.0	8.0-10.0	
CF-10	0.10 max.	18.0-20.0	8.0-10.0	
CF-16	0.16 max.	18.0-20.0	8.0-10.0	
CF-20	0.20 max.	18.0-20.0	8.0-10.0	
CF-7Se	0.07 max.	18.0-20.0	8.0-10.0	Se 0.20-0.35
CF-7C	0.07 max.	18.0-20.0	8.0-10.0	Cb 8 × C *(o)*
CF-7M	0.07 max.	18.0-20.0	8.0-10.0	Mo 1.5-3.5
CF-10M	0.10 max.	18.0-20.0	8.0-10.0	Mo 1.5-3.5
CF-16M	0.16 max.	18.0-20.0	8.0-10.0	Mo 1.5-3.5
CG-7	0.07 max.	20.0-22.0	10.0-12.0	
CG-10	0.10 max.	20.0-22.0	10.0-12.0	
CG-16	0.16 max.	20.0-22.0	10.0-12.0	
CG-16Se	0.16 max.	20.0-22.0	10.0-12.0	Se 0.20-0.35
CG-7C	0.07 max.	20.0-22.0	10.0-12.0	Cb 8 × C *(o)*
CG-7M	0.07 max.	20.0-22.0	10.0-12.0	Mo 1.5-3.5
CG-10M	0.10 max.	20.0-22.0	10.0-12.0	Mo 1.5-3.5
CG-16M	0.16 max.	20.0-22.0	10.0-12.0	Mo 1.5-3.5
CH-10	0.10 max.	22.0-26.0	12.0-15.0	
CH-20	0.20 max.	22.0-26.0	12.0-15.0	
CH-10C	0.10 max.	22.0-26.0	12.0-15.0	Cb 8 × C *(o)*
CH-10M	0.10 max.	22.0-26.0	12.0-15.0	Mo 1.5-3.5
CK-25	0.25 max.	23.0-27.0	19.0-22.0	
CM-25	0.25 max.	8.0-11.0	19.0-22.0	
CN-7	0.07 max.	18.0-22.0	20.0-30.0	May contain others
CT-7	0.07 max.	13.0-17.0	34.0-37.0	
HB	n.s.*	18.0-22.0	2.0 max.	
HC	n.s.*	26.0-30.0	4.0 max.	
HD	n.s.*	26.0-30.0	3.0- 6.0	
HE	n.s.*	26.0-30.0	8.0-11.0	
HF	n.s.*	18.0-23.0	8.0-11.0	
HH	n.s.*	23.0-27.0	11.0-14.0	
HI	n.s.*	26.0-30.0	14.0-17.0	
HK	n.s.*	23.0-27.0	19.0-22.0	
HL	n.s.*	28.0-32.0	19.0-22.0	
HN	n.s.*	18.0-22.0	23.0-26.0	
HP	n.s.*	28.0-32.0	29.0-31.0	
HS	n.s.*	8.0-12.0	29.0-32.0	
HT	n.s.*	13.0-17.0	33.0-37.0	
HU	n.s.*	17.0-21.0	37.0-41.0	
HW	n.s.*	10.0-14.0	58.0-62.0	
HX	n.s.*	15.0-19.0	64.0-68.0	

*n.s. means not specified.

(m) All of the above designations apply to type compositions and no attempt is made to cover elements such as manganese, silicon and (in the case of heat resistant alloys) carbon.

(n) Designations with the initial letter C indicate alloys generally used to resist corrosive attack at temperatures less than 1200° F. Designations with the initial letter H indicate alloys generally used under conditions where the metal temperature is in excess of 1200° F.

(o) Columbium 1.00% max.

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STAINLESS
ALLOY STEELS
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Engineering Properties of "A" and "L" Nickel*

Data from International Nickel Co., Inc.

WROUGHT NICKEL used throughout American industry is commercially pure metal, specifically "A" nickel to distinguish it from electrolytic nickel and from special alloys like "D" nickel containing 4.5% manganese and from "Z" nickel, an age-hardenable alloy containing 98.0% nickel. A carbon-free variety (carbon 0.02% max.) is known as "L" nickel to distinguish it from "A" nickel.

Nominal Composition of "A" Nickel*

	Wrought	Cast
Nickel (plus cobalt)	99.4	96.7
Copper	0.1	0.3
Iron	0.15	0.5
Manganese	0.2	0.5
Silicon	0.05	1.5
Carbon*	0.1	0.5

Magnetic Properties

Initial permeability, μ_0	110
Maximum permeability, μ_m	600
Saturation, gausses	6100
Hysteresis loss at saturation, ergs per cu.cm.	3000
Residual induction, gausses	3600
Coercive force, oersteds	3.4
Curie temperature, ° C.	360

Endurance Limit and Apparent Corrosion Fatigue Limit of Monel, Nickel and Carbon Steels in Air, in Fresh Water and in Brackish Estuarine Water *(a)*

Material	Condition	Endurance Limit, Psi. for 10^8 Cycles	Apparent Corrosion-Fatigue Limit, Psi. for 10^8 Cycles	
			Fresh Water	Brackish Water
Nickel	Annealed	33,000	21-24,000	20-22,000
	Cold worked	50,000	21-24,000	20-22,000
Monel	Annealed	36,000	21-24,000	27-29,000
	Cold worked	50,000	21-24,000	27-29,000
Carbon steels		25-42,000	16-24,000	6- 8,000

(a) From "Corrosion Fatigue of Non-Ferrous Metals," by D. J. McAdam, Jr., *Proceedings*, American Society for Testing Materials, Vol. 27, 1927, p. 122.

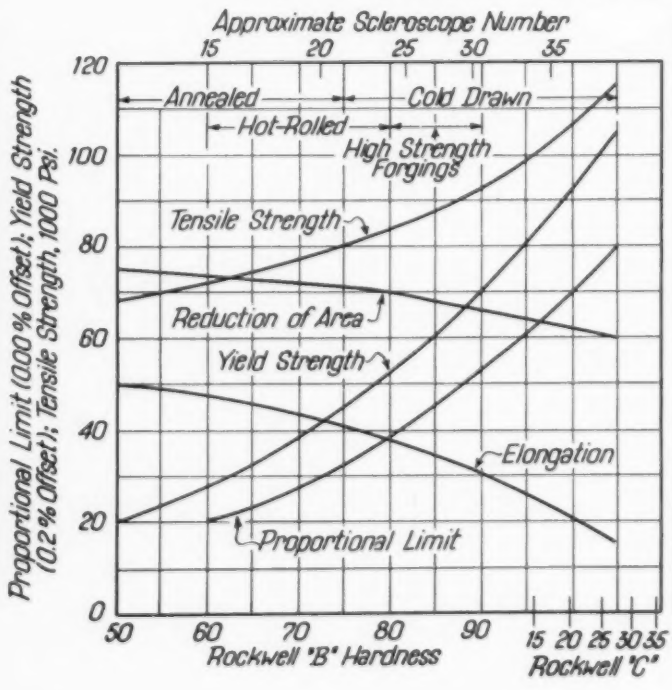
Physical Constants of "A" Nickel*

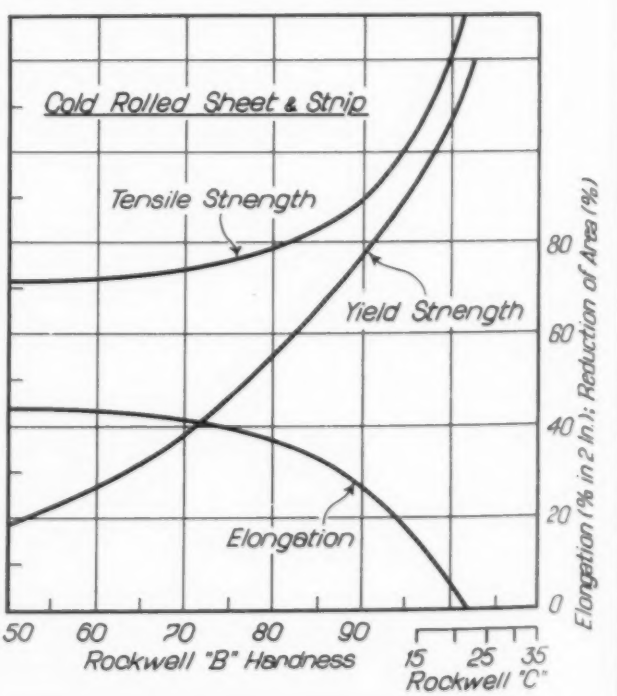
Specific gravity	8.89
Density, lb. per cu. in.	0.321
Melting range	
degrees Fahrenheit	2615 to 2635
degrees Centigrade	1435 to 1445
Specific heat at (80° to 212° F.) (27° to 100° C.)	0.113
Heat expansion coefficient	
at (80° to 212° F.), per ° F.	0.0000072
at (27° to 100° C.), per ° C.	0.000013
Thermal conductivity	
at (80° to 212° F.), Btu./sq.ft./hr./° F./in.	420
at (27° to 100° C.), cal./sq.cm./sec./° C./cm.	0.145
Electrical resistivity	
at 68° F., ohms/circ. mil. ft.	57
at 20° C., microhms/cm.³	9.5
Temperature coefficient of electrical resistivity	
per ° F.	0.0024 to 0.0028
per ° C.	0.0043 to 0.0050
Modulus of elasticity	
in tension, psi.	30,000,000
in torsion, psi.	11,000,000
Poisson's ratio	0.31

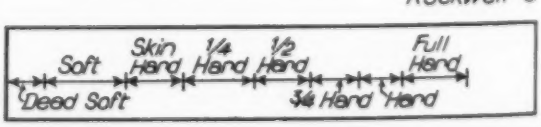
Short-Time High Temperature Tensile Properties

Test Temperature	Tensile Strength	Yield Strength (0.2% Offset)	Elongation in 2 In.
Room	73,000 psi.	24,000 psi.	49%
200° F.	77,000	21,000	52
300	76,000	21,000	46
400	79,000	23,000	49
500	76,000	24,000	48
600	83,000	22,000	50
700	80,000	22,000	50
800	76,000	21,000	52
900	65,000	20,000	51
1000	46,000	17,000	55
1200	34,000	15,000	57
1400	27,000	12,000	61
1600	16,000		76
1800	8,000		91

Average Tensile Properties and Hardness of Wrought "A" and "L" Nickel*







*Values for "L" nickel are essentially the same as for "A" nickel, since the only difference in chemical composition is the carbon content.

Wrought Copper Alloys With High Silicon

By A. G. H. Andersen
Oakdale, N. Y.

AS NOTED in the article in 1939 "● Metals Handbook", page 1420, commercial wrought copper-silicon bronzes usually are ternary or complex alloys containing 3% silicon or less, with iron, zinc, manganese or tin in smaller amounts, seldom more than 1%.

Among the binary alloys of copper and silicon investigated in the past, those which are low enough in silicon to keep them within the range of alpha solid solutions have received most attention — although, as it will appear from the work to be described, the alloys of higher silicon possess very attractive properties. The boundary line between the alpha range and nonhomogeneous or two-phase ranges in the equilibrium diagram of binary alloys of copper and silicon slants back from a little over 5% silicon at about 1375° F. (750° C.) to about 3¾% silicon at 750° F. (400° C.). This boundary may be shifted considerably by impurities and by deliberately added components. Thus, the present author, together with A. W. Kingsbury, found that when iron is added to copper-silicon alloys, not only are new phases containing iron introduced, but iron also enters the alpha-copper phase and expands its range on the ternary diagram toward higher silicon contents (*Transactions*, A.I.M.E., 1943, p. 38). When manganese in corresponding amounts is added to copper-silicon alloys, its effect on the alpha solid solution boundary, within a couple of per cent of the true binary, is more irregular though less pronounced, except at lower temperatures.

One well-known commercial alloy ("Everdur") contains 4% silicon and 1% manganese; another ("Olympic") contains 4¼% silicon and 1% zinc. When larger amounts of zinc or appreciable amounts of other elements are employed, the silicon content is customarily reduced into the range of 3½%. Thus, in wrought "P.M.G.", different types of which may contain from 0.5 to 1.2% iron, the silicon content in various alloys ranges from 1.2 to 3.2%. The presence of a second constituent, which on occasion may occur in alloys above 4% silicon, is not necessarily fatal to their mechanical properties; for, although some silicon bronzes, notably those containing manganese, may be essentially single-phase alloys, others like the P.M.G. metals may contain appreciable amounts of iron silicides and other intermetallic compounds.

Copper-silicon alloys containing 4 to 6% silicon have been briefly studied by E. Voce (*Journal* of the Institute of Metals, 1930, p. 331). He hot rolled a 4.6% silicon alloy, but could not cold roll it; he succeeded in cold rolling an alloy containing 5% silicon and 1½% manganese, though the sheet was not classed as of good quality. Another containing 6% silicon allowed neither hot rolling nor cold rolling; however, still another containing 5% silicon was hot rolled at 1380° F., but cracked when cold rolling was attempted. Voce classified the alloys as follows:

6% silicon; weak and completely brittle due to the presence of large amounts of gamma.

4.8% silicon; very strong with fairly good ductility.

4.5% silicon; very similar in properties to admiralty gun metal.

3% silicon; fairly strong and very ductile.

When starting on an investigation for the Phelps Dodge Copper Products Corp. some years ago, it appeared to the writer that alloys of 4 to 5% silicon deserved consideration, not only for the sake of possible commercial usefulness but also for obtaining reference data in the study of the ternary alloys. In this investigation the alloys were crucible melted under a heavy layer of charcoal. Raw materials were electrolytic copper and silicon, taken from the stock used in commercial manufacture of P.M.G. metal. Incidental impurities were therefore minor, and on the order of

Fig. 1 — As Cold Drawn

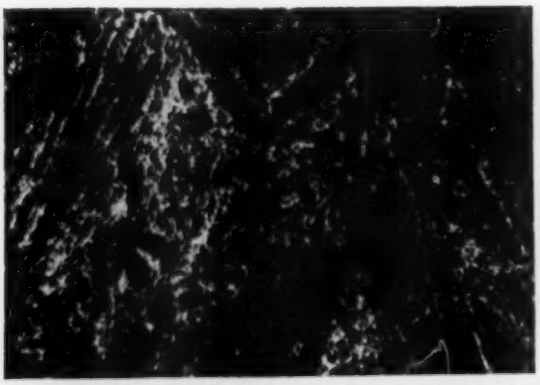


Fig. 2 — Annealed 2 Hr. at 750° F.

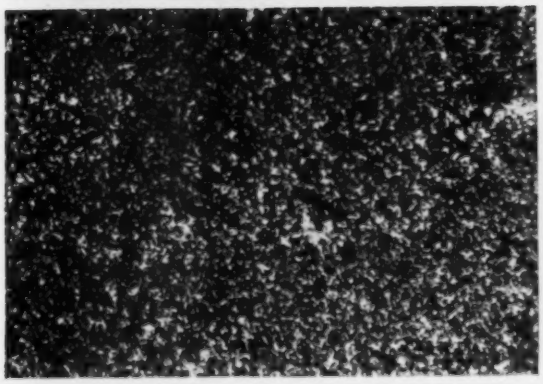


Fig. 3 — Annealed 2½ Hr. at 930° F.

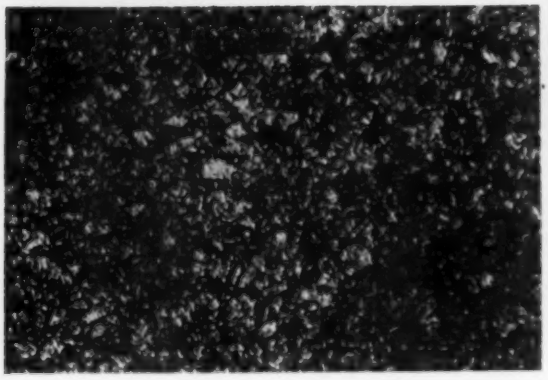


Fig. 4 — Annealed 2½ Hr. at 1110° F.

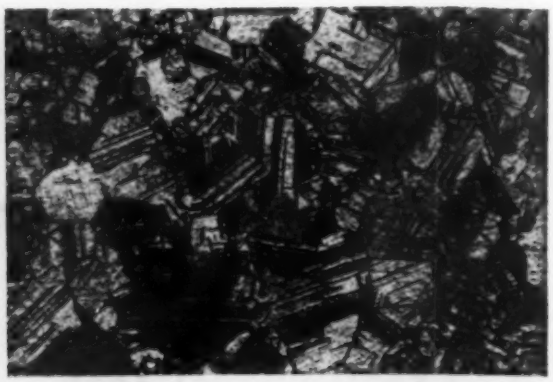


Fig. 5 — Annealed 2½ Hr. at 1290° F.

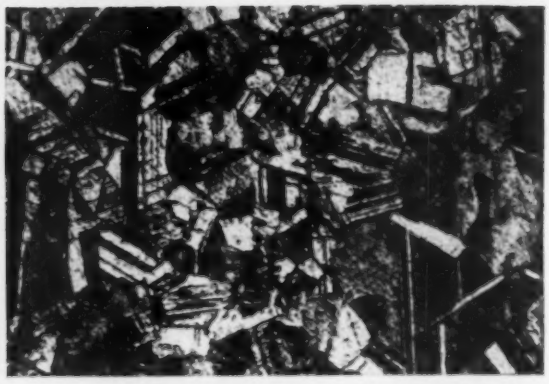


Fig. 6 — Annealed 2½ Hr. at 1475° F.

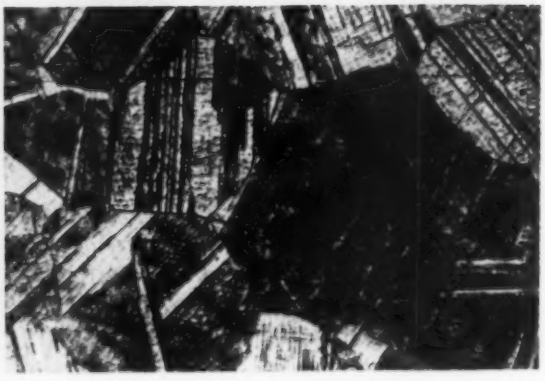


Fig. 1 to 6 — Microstructure of 4.15% Silicon Alloy, Cold Drawn From ⅞ to ½ In. Diameter (67.4% Reduction). 100 diameters; vertical illumination

amounts contained in the commercial silicon bronzes. Iron was approximately 0.01% — practically all of it derived from the silicon metal used in the compounding — the other elements were even lower.

The experimental alloys were poured at 2000 to 2100° F. (1100 to 1150° C.) into 2½x2½-in. tapered steel ingot molds, or into graphite molds, 3-in. diameter. The ingots, which weighed about 16 lb., were scalped, soaked 1 to 3 hr. at 1425° F. (775° C.) — the higher the silicon content the longer the soaking time required — hot forged to ⅞-in. diameter at 1450 to 1150° F. (790 to 620° C.), starting with light hammer blows and finishing at a dark cherry red.

The hot forged rods were sized, annealed at 1475° F. (800° C.) for 2½ hr. and pickled in a 50% solution of sulphuric acid containing 50 g. per l. of sodium bichromate.

Following this preparatory treatment, the alloys were cold drawn to various degrees of reduction and samples tested for tensile properties after each draw. Drawing was done on commercial drawbenches as well as in the laboratory, although only bars from the latter were subsequently tested. Alloys containing over 4½% silicon are prone to be overworked in swaging the point and thus to break in the grips of the commercial drawbench.

Short lengths of the experimental alloys were drawn at 6 in. per min. on a tensile testing machine through standard steel dies held in a

Tensile Strength, 1000 Psi.

Table I — **Rockwell Hardness of Cold Drawn and Annealed Rods**

Silicon	Reduction	Hardness, B Scale					
		Cold Drawn	Annealed 2 Hr. at				
			752° F.	932° F.	1112° F.	1292° F.	1472° F.
4.15%	67.4%	98	90	73	63	60	54
4.31	67.4	94	97	79	68	60	52
4.95	38.3	92	94	91	81	62	53

stirrup hung from the upper crosshead of the machine. In drawing to ½-in. diameter, three to five passes for 55 to 77% total reduction could be given between anneals. Slow drawing by the tensile testing machine keeps the bars comparatively cool and hence they harden less than they would on a production drawbench.

Table I gives the annealing behavior of three alloys. The temperature required for complete softening evidently remains virtually unchanged over the composition range of 4 to 5% silicon and is close to 1475° F. (800° C.). The temperature at which initial softening sets in, on the other hand, increases from 750° F. (400° C.) for the 4.15% silicon alloy to about 930° F. (500° C.) for the 4.95% silicon alloy. Microstructures obtained on annealing the 4.15% silicon alloy are shown in Fig. 1 to 6. Similar micrographic examination of all three alloys shows that the temperatures at which recrystallization begins correspond to the above mentioned temperatures of initial softening.

Figures 7 to 9 show the mechanical properties of hot forged rods, annealed and cold drawn to the per cent reduction indicated.

The effect of cold drawing and annealing prior to further cold drawing is shown in Fig. 10 for the 4.4% silicon alloy. It was first cold drawn to 66% reduction, then annealed at 1110° F. (600° C.) for 45 min. and again cold drawn variously to 26% and on up to 66% reduction. The tensile strength after this treatment increases from 110,000 psi. for 26% reduction to 142,000 psi. for 66% reduction, as shown in the full lines, Fig. 10. After annealing the same alloy at 1475° F. (800° C.) and cold drawing to 26 and 66% reduction respectively, the ten-

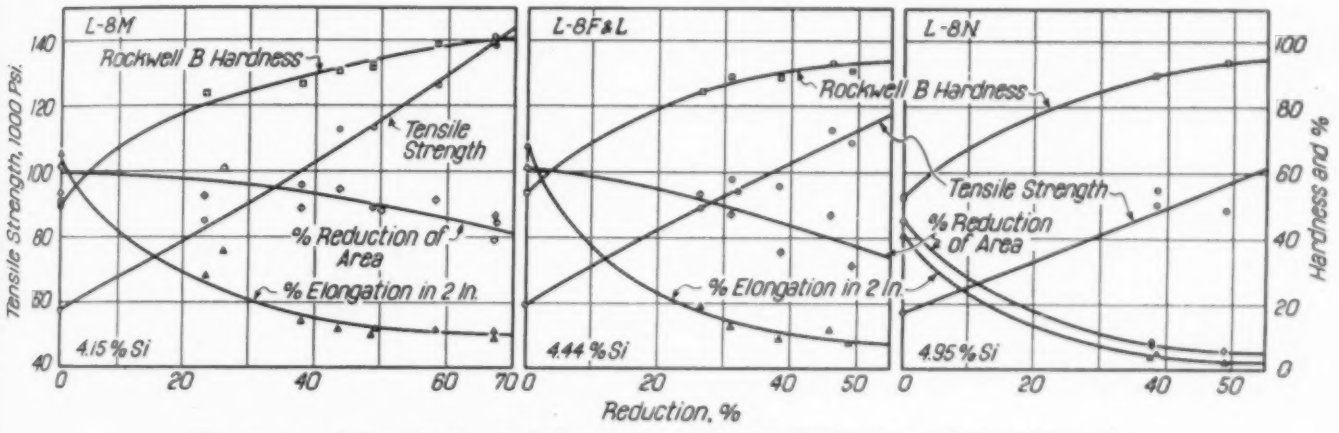


Fig. 7, 8 and 9 — Mechanical Properties of Hot Rolled Rods of 4.15, 4.44, and 4.95% Silicon Alloys, Respectively, and After Cold Drawing Various Reductions

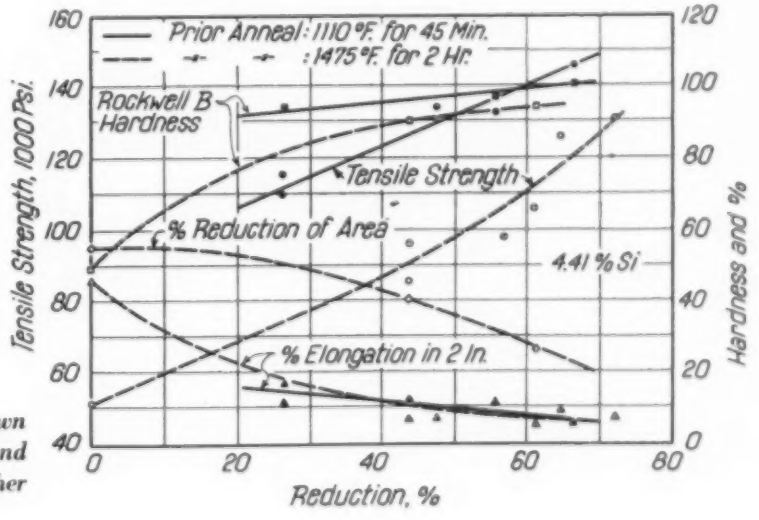


Fig. 10 — 4.41% Silicon Rods, Cold Drawn to 66% Reduction, Were Annealed at 1110 and at 1475° F. and Then Cold Drawn Further

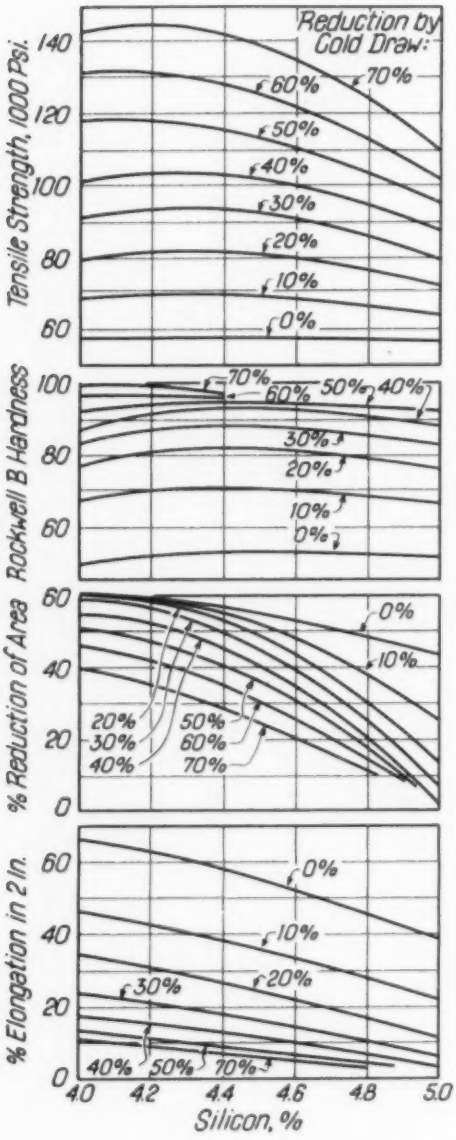


Fig. 11 (Left)— Influence of Silicon Content and Amount of Cold Reduction on Mechanical Properties (No Relief Annealing)

Table II — Permanent Set of 4.33% Silicon Alloy After Repeated Loadings

Cold Reduction	2-Hr. Anneal	Load Cycle	Stress	Deviation From Tangency	Permanent Set*
16%	750° F.	First	40,000	0.001,7	0.000,55
36	750° F.	First	45,000	0.001,6	0.000,35
		Second	55,000	0.003,8	0.001,05
		Third	40,000	0.001	0.000,075
55½	660° F.	First	40,000	0.000,35	†
		Second	60,000	0.000,65	0.000,07
		Third	70,000	0.000,85	0.000,08
55½	570° F.	First	40,000	†	†
		Second	60,000	0.000,3	0.000,04
		Third	70,000	0.000,5	0.000,08
55½	None	First	40,000	†	†
		Second	60,000	0.000,6	0.000,01
		Third	70,000	0.000,7	0.000,08

*After relief of load; value in inch per inch.
†Too small for accurate determination.

sile strengths are much lower — about 70,000 and 120,000 psi., respectively. Hardness is correspondingly lowered, although elongation values are still high. (See dotted lines in Fig. 10.)

A summary of the relations among the mechanical properties for alloys of varying silicon content and various degrees of cold drawing is given in Fig. 11. (None of the specimens for which data are plotted in Fig. 7 to 11 were relief annealed.)

Relief annealing, by which the tensile strength of hard drawn bars is reduced and their ductility increased, can be utilized to equalize the strains remaining after drawing, rendering them less susceptible to season cracking. A further noteworthy feature is the low permanent set acquired by test pieces after relief of stresses well above the load where the stress-strain curve deviates from tangency. Figure 12 shows stress-strain diagrams for repeated loadings of a 4.33% silicon alloy after 55½% of cold work and an anneal at 660° F. Even though the loadings have been carried up to a degree at which the stress-strain curve shows decided curvature during the unloading cycle, the permanent set is smaller than would have been expected from the "plastic" flow indicated in the loading curve. Take for instance the third curve; after loading to 70,000 psi., deviating from the proportional relationship by 0.000,85 in. per in., and then unloading, the *permanent* set amounts to 0.000,08 in. per in. This exceptionally low permanent set appears to be characteristic of these copper-silicon alloys; Table II gives representative values for the 4.33% alloy.

Relief annealing should be applied when stress-corrosion or season cracking is to be resisted. The alloys after relief annealing not only pass the ordinary mercurous nitrate test, but when put under stress in a frame, as shown in Fig. 13, and immersed in the

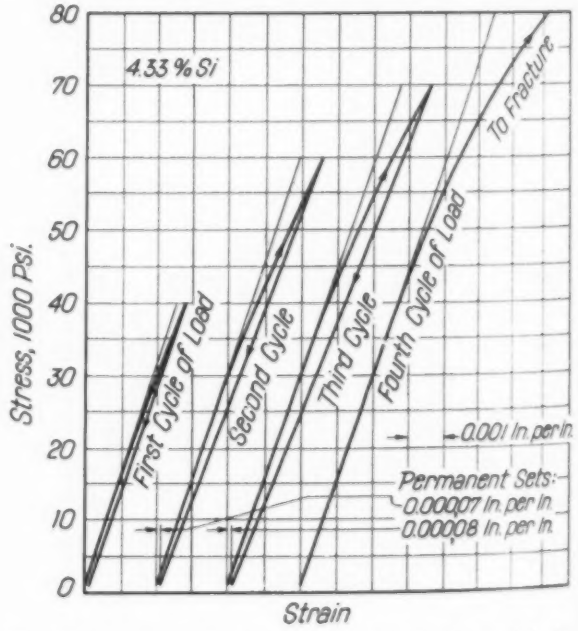


Fig. 12 — Copper-Silicon Alloys Acquire Surprisingly Small Permanent Set After Loading Considerably Beyond Point of Tangency on Stress-Strain Curve

solution, give the excellent results shown in Table III, below.

In this connection the resistance of the alloys to ordinary corrosion upon immersion in acid solutions and to the salt spray test may be of interest. Expressed in inches penetration per year, the corrosion rates found after extensive tests may be summarized as follows: In the salt spray chamber the rates drop rapidly from 0.0015 initially, to 0.0013 after 30 days and reach about 0.001 after 90 days.

In cold concentrated sulphuric acid and in a 10% sulphuric acid solution, the penetration rates after 60 days are 0.03 and 0.003, approximately. In a 2% sulphuric acid solution, continuously aerated, the rate after 60 days is 0.075.

Corresponding figures for hydrochloric acid are 0.006, 0.18, and 0.17 for 1, 30 and 90 days, respectively. In concentrated aerated hydrochloric acid the rate is 0.10 after 60 days.

In order to round out the picture of the physical properties of these alloys, the results of a few collateral tests may be mentioned in concluding. The endurance limit, determined at Battelle Memorial Institute on an alloy cold drawn to 30% reduction and relief annealed for 2 hr. at 750° F. (400° C.) is 29,500 psi. Shearing strength was determined very accurately in a specially designed grip, and averaged about 43,000 psi. for the annealed alloys. The hardest drawn rods of 4% silicon alloy had shearing strength of 68,000 psi.; the 5% alloy was weaker — 53,000 psi. in hard drawn condition. Electrical conductivity is about 6% of the copper standard. Density ranges from 10.75 to 10.77.

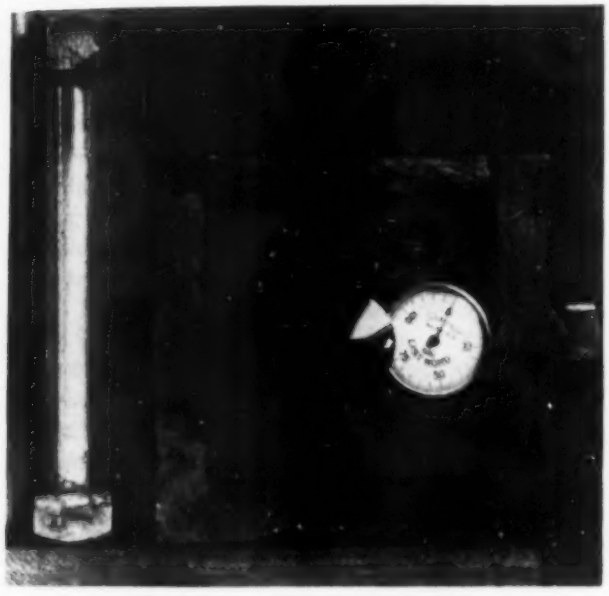


Fig. 13 — Frame for Stressing Bolt Specimens While Immersed in Mercurous Nitrate. Bolt at left; strain gage attached to bolt in frame

Machinable, Although Quite Elastic

After drawing and relief annealing, the alloys are easily machined — in this respect compare well with free machining brass. This is a point of the greatest interest, machinability being better than the other commercial silicon bronzes with which I am familiar. The second property that will appeal to designers, doubtless, is the low permanent set after overload (Fig. 12 and Table II).

These higher copper-silicon alloys probably will require a somewhat different processing than do the lower silicon alloys, and this may involve some extra care. After the binary copper-silicon diagram has become known in greater detail, this should cause no serious difficulty. The tensile properties start to fall off at slightly higher than 4% silicon and, judged purely on the basis of ultimate strength and ductility, still higher silicon compositions would not appeal to the trade unless the users should appreciate the free machining qualities and the extremely low permanent set.

Table III — Stress-Corrosion Test in Acid Mercurous Nitrate Solution

Alloy	Condition	Strain, In. Per In.	Estimated Stress	Min. Immersed	Appearance
4.15% Si	67% reduction	0.0015	20,000	30	OK
		0.0030	37,000	+15	OK
		0.0040	49,000	+30	OK
4.33% Si	55.5% reduction; relief annealed 2 hr. at 350° C.	0.0011	15,000	15	Broken
4.33% Si	30.4% reduction; relief annealed 2 hr. at 400° C.	0.0011	15,000	15	OK
		0.0021	26,000	+15	OK
		0.0030	35,000	+15	Broken
4.48% Si	Annealed 2 hr. at 800° C.	0.0009	10,000	15	OK
		0.0015	12,500	+15	Broken
4.48% Si	39.6% reduction; relief annealed 2 hr. at 300° C.	0.0011	15,000	15	OK
		0.0021	30,000	+15	OK
		0.0030	40,000	+15	Broken
4.95% Si	38% reduction	0.0015	15,000	15	OK
		0.0030	28,000	+25	Broken

By Ernest E. Thum
Editor, Metal Progress

A View of the Future of Metals

PARADOXICALLY enough, the long future of all our common metals will be profoundly influenced by the uses we find for one or two of the rare ones — namely uranium and thorium. Wholly aside from the undoubted fact that if we let these metals explode there will not be enough of our machine-civilization left for salvage, and neglecting the important influences on all technical and scientific progress reasonably to be anticipated by an abundance of radioactive chemical elements, we can certainly anticipate fundamental changes in our present methods of power production. Here is where atomic distintegration comes closest to modern metallurgy, for heat and power are — with labor, taxes and management — the principal costs in all metal production.

Admittedly, the engineer whose information about nucleonics is what General Groves allows to be printed is in no position to know whether more power goes into the uranium plants for the necessary concentration and refining separations than comes out of the purified metal as heat. As a matter of fact, a favorable heat balance is not important when the plant is to make bombs. However, the American representative on the United Nations Atomic Energy Commission has published preliminary estimates by his engineering staff showing that, on the basis of present knowledge, a 75,000-kw. plant could be built which will produce power at 0.8¢ per kw-hr. This compares with 0.65¢ for a steam plant of the same size using bituminous coal at $7 per ton delivered. The thoughtful engineer can readily foresee, what with the rising price of coal and the certain improvements in nuclear engineering, that these two costs may readily be reversed in the not distant future, even in regions relatively close to coal deposits.

Nuclear power plants, requiring but trivial amounts of fuel and little water, will of course be important aids in the decentralization of the metallurgical industry — freeing it from its present intimacy with coal, gas and oil fields. More than that is the foreseeable public ownership of *all* power resources. Since the Atomic Energy Act of 1946, already enacted into law, declares that the ownership of fissionable elements is exclusively governmental, private ownership of coal, oil, gas and water power becomes an economic impossibility — those industries in turn will, sooner or later, be absorbed by the State.

What will be the eventual effect of this public monopoly of power on the metal industries can hardly be imagined, but at any rate it will be enough to warrant the statement made at the outset, namely, that the rare heavy metals will have the most profound influence on the future of our common ones.

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During the last war, the iron and steel industry entered a stage in its history that was experienced in World War I by the other important metallurgical branches — namely, the copper, zinc, and lead industries. All of these have now mined out their bonanza deposits, and their global position has changed from world leadership with exportable surplus to a dependence by the United States on imports of ore or metal, and tariff subsidies to maintain the home industry. Iron and steel are approaching that phase. It will be characterized by the growth of blast furnace and steel plants located on tidewater (to utilize cheap foreign ores), the gradual movement of the inland steel industry toward the remaining large and cheap ore supplies (the increase in relative importance of plants nearer the Minnesota, Alabama and Utah deposits), and the increased differentials in the remaining plants due to higher costs of using or beneficiating low grade ores and the steadily increasing costs of transportation.

Political promotions during the war made no headway in the development of direct iron to

replace the blast furnace, nor is there any such substitution to be expected in modern tonnage operations. From the standpoint of science, the iron and steel industry — in fact, all metallurgical industry — progressed no faster (if as fast) during the war years than during a similar prewar period. The wartime urge for tonnage production absorbed almost all energies. No important difference exists between the wartime demands and the peacetime consumption, so the problems of reconversion were relatively simple — largely consisting of shutting down the older obsolescent departments or units and slight modifications of the more economical plants built during the war. Some minor delays were experienced in reconverting, such as the change back again of the sheet mills from their wartime job of turning out steel plate, but present "shortages" in this, that, or the other class of product are due to temporarily dislocated demand and the desire of manufacturers to produce as much of the lower-cost, higher-price schedules as practicable.

Army, navy and aircraft material and munitions require a much larger proportion of high grade alloy steels than the prewar peacetime market, and this caused a large expansion in electric furnace capacity (suitable for the alloy steels). Fortunately, prewar studies had clarified the essential action of the various important alloying elements in steel, and so enabled us to use to best advantage our limited supply. Knowledge of the essentials of manufacturing — quality control of steel refining, both in openhearth and electric furnace — became widespread. One can foresee that electric furnaces will gradually become our standard steel refining furnace after the recently acquired information about quick-smelting processes becomes more widespread. Likewise, the relative cost of heat from the various energy sources will cause coal and coke to be replaced by electricity generated by water power or by central stations at the coal mine, and eventually by atomic energy. Furthermore, higher quality steels will be more intelligently used in order to reduce the weight (cost) of metal. The steel plants specializing in quality steels will therefore prosper at the expense of those making ordinary grades.

In all branches of the metal industry will be an insistent urge toward labor-saving mechanization to combat not only the higher wage rates, but also the relatively low production per man-hour. Servomechanisms and automatic controls are indeed indispensable when speeds of production increase — it is easy to go beyond the rate at which a man can observe and react. Production in all branches must certainly be greater than ever before if we are to maintain an economy of 60 million gainfully employed citizens.

Before passing to the nonferrous metals, a brief consideration of the principal alloying elements is in order. (Of all these, molybdenum and silicon are the only ones in which the United States is self-sufficient in supply — even manganese, absolutely necessary "medicine" in every pound of steel of whatever kind, must be imported.) Nickel, of course, comes from just over the Canadian border, but it is an import as well as chromium, manganese, vanadium, and tungsten. Attention is now being given to the problem of governmental stockpiles of these ores — paralleling a similar agitation after World War I. It is to be hoped that something more tangible will result than did previously. Such metals could be used as pay for exports of food, machinery, and manufactured goods — or at least it would seem so. While much can be done to conserve new alloys and recover them from scrap, as was proven during the last few years, the costs of maintaining a safe stockpile of essential alloying metals are too great for the metallurgical industry to shoulder alone.

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In the nonferrous industry (except for aluminum and magnesium), the situation as of today

is so confused by scarcities, real or imposed, that reasonably accurate forecasting is impossible, except that an expanding economy will *demand* more and more metal. For example, a full supply of much-needed tin (of which none is mined in the United States) will be delayed until 1950, since the dredges in Malaya, where the tin ore is found, were destroyed during the war. In fact, tin has been so strictly rationed for years that industry has found out how to get along without much of it, and made such good shift with such substitutions as electrolytic tin-plate, silver solders and copper brazing, and thin-walled bearings, low in tin, that some of these older markets are permanently curtailed — certainly lost to any high priced importation.

Production of zinc and lead is now far below current demands due to exhaustion of rich ore supplies in the United States and lack of miners. Lead is mixed up in a typical bureaucratic snafu, wherein ceilings are lower than prewar prices. This prevents maximum production from either mines or secondary sources even though there is a complicated system of premiums paid for new metal by the U. S. Treasury. Likewise, imports are regulated by informal governmental agreements, so a world market and price can hardly be said to exist. Lead is a metal whose uses are built about its unique specific properties, such as corrosion resistance, fusibility, mass, antifrictional nature, and for each of these a substitution is indeed difficult. Add to this the fact that no important new lead mining district has been opened up anywhere in the world during the last generation, and the conclusion seems to be that long lean years are ahead.

Lastly, the American copper industry was shut down for months by strikes at mines and refineries. Until such matters as mentioned, affecting these principal nonferrous metals, are corrected and a free flow of ingot metal re-enters commerce, there is bound to be an almost universal slowdown of production of durable goods, for one can hardly mention a machine or tool that does not require some of these common metals as an essential.

In the long view, the final and correct adjustment of nonferrous supplies must await some fundamental decisions by the American public through its political parties. That will take, doubtless, a long time, if, indeed, it will ever be done. It is hard for any mining and smelting community to realize that its underground riches are not inexhaustible. Yet the Michigan copper country and innumerable ghost towns in the West prove the fact. How much better would it be to maintain a smaller industry that would leave some of our ores in the ground, ready to be mined during the next emergency by an industry that knows how, and to import the surplus metal we need but cannot readily mine, accepting it as pay for some of the things we can send to foreign peoples. But any realistic observer of American ways will know that such a course will never be taken. We will, as of yore, face the next emergency unprepared. One thing that may be expected of it, though, is that the emergency will be short, and if we let it happen the survivors won't care much about ore supplies.

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Aluminum and magnesium plants overexpanded during the war — magnesium at least tenfold. Entrance of Reynolds Metals Co. into the aluminum metal industry, in competition with Aluminum Co. of America, is bound to make for progress, although Alcoa's prewar history was one of enlightened development and continuous price reduction. There is also doubtless room for a second large manufacturing interest — the nearby potential demand for aluminum is possibly three times the prewar. During the war, the first practicable method of smelting low grade ore was developed; "aluminum from clay" is now a reality, although the expensive process will doubtless be reserved for our meager supply of lean ore if, as and when needed, and reliance placed, as in the past, on high grade bauxite imported from South America. Due to long and intensive study by Alcoa's engineers and scientists, the knowledge about properties and uses of aluminum and its alloys has reached an extremely high level — it might almost be said that it is near the ceiling, for the best alloy developed during the war to meet the insistent urge of aircraft builders was only about 10% stronger than the prewar best. One cannot, therefore, confidently predict any epoch-making discovery that will upset the present commercial balance between the light metal aluminum and the heavier ones — at least in the uses of metals for machinery and structures.

Magnesium, however, is in its infancy as far as development and knowledge of its properties are concerned. Much of the existing smelting capacity was built hastily to satisfy the supposed needs of wartime incendiary bombs, but never used and it probably will fall apart from old age before it will be used. The important wartime development was the production of cheap magnesium from sea water — a truly inexhaustible source. Future trends are sure to be a series of price reductions in ingot and fabricated forms, as the manufacturing art becomes better understood, and of widespread applications as knowledge of magnesium's potentialities increases. ●

Crystallography of the Chemical Elements—I

As tabulated by William Hume-Rothery in "Structure of Metals and Alloys"
Monograph No. 1, Institute of Metals, London, 1945

Modified by references to literature to May 1946 by H. C. Vacher

Atomic No. and Element	Electron Arrangement in Free Atoms	Crystal Structure: Allotrope	Crystal Structure: Type #	Crystal Structure: Space Group	Lattice Constants: Kx-Units: a	b	c or Axial Angle	Temperature °C.	Axial Ratio b/a, c/a	Coordination No.	Interatomic Distances: d_1	d_2	Atomic Diameter
1, Hydrogen†	1	—	○	?	3.75	—	6.12	-271	—	—	—	—	—
GROUP 0 IN PERIODIC SEQUENCE													
2, Helium†	(2)	—	◎	D^4_{6h}	3.57	—	5.83	-271.55	1.633	6,6	3.57	3.57	—
10, Neon†	(2)(8)	—	▣	O^5_h	4.52	—	—	-268	—	12	3.198	—	—
18, Argon	(2)(8)(8)	—	▣	O^5_h	5.42	—	—	-233	—	12	3.83	—	—
36, Krypton	(2)(8)(18)(8)	—	▣	O^5_h	5.68	—	—	-191	—	12	4.02	—	—
54, Xenon	(2)(8)(18)(18)(8)	—	▣	O^5_h	6.24	—	—	-185	—	12	4.41	—	—
86, Radon	(2)(8)(18)(32)(18)(8)	—	—	—	—	—	—	—	—	—	—	—	—
GROUP IA IN PERIODIC SEQUENCE													
3, Lithium†	(2)1	—	▣	O^9_h or T^6_d‡	3.5017	—	—	20	—	8	3.0326	—	3.13
11, Sodium	(2)(8)1	—	▣	O^9_h	4.2820	—	—	20	—	8	3.708	—	3.83
19, Potassium	(2)(8)(8)1	—	▣	O^9_h	5.333	—	—	Room	—	8	4.618	—	4.76
37, Rubidium	(2)(8)(18)(8)1	—	▣	O^9_h	5.62	—	—	-173	—	8	4.87	—	5.02
55, Cesium	(2)(8)(18)(18)(8)1	—	▣	O^9_h	6.05	—	—	-173	—	8	5.24	—	5.40
87, Virginium	(2)(8)(18)(32)(18)(8)1	—	—	—	—	—	—	—	—	—	—	—	—
GROUP IB													
29, Copper	(2)(8)(18)1	—	▣	O^5_h	3.6078	—	—	18	—	12	2.551	—	2.551
47, Silver	(2)(8)(18)(18)1	—	▣	O^5_h	4.0779	—	—	25	—	12	2.8835	—	2.885
79, Gold	(2)(8)(18)(32)(18)1	—	▣	O^5_h	4.0704	—	—	25	—	12	2.8782	—	2.878
GROUP IIA IN PERIODIC SEQUENCE													
4, Beryllium	(2)2	α*	◎	D^4_{6h}	2.2810s	—	3.57714	18	1.56820	6,6	2.221	2.281	2.25
		○	—		7.1	—	10.8	Room	1.52	—	—	—	—
12, Magnesium	(2)(8)2	—	◎	D^4_{6h}	3.2030	—	5.2002	25	1.62354	6,6	3.1906	3.2030	3.20
20, Calcium	(2)(8)(8)2	α*	▣	O^5_h	5.56	—	—	20	—	12	3.93	—	3.93
		β	—	—	—	—	—	Between 300-450	—	—	—	—	—
		γ	◎	D^4_{6h}	3.98	—	6.52	450	1.638	6,6	3.98	3.99	3.93
38, Strontium	(2)(8)(18)(8)2	—	▣	O^5_h	6.07s	—	—	Room	—	12	4.296	—	4.296
56, Barium	(2)(8)(18)(18)(8)2	—	▣	O^9_h	5.01s	—	—	Room	—	8	4.343	—	4.48
88, Radium	(2)(8)(18)(32)(18)(8)2	—	—	—	—	—	—	—	—	—	—	—	—
GROUP IIB													
30, Zinc	(2)(8)(18)2	—	◎	D^4_{6h}	2.6595	—	4.93685	25	1.85631	6,6	2.6595	2.9070	2.748
48, Cadmium	(2)(8)(18)(18)2	—	◎	D^4_{6h}	2.9731	—	5.60694	25	1.88588	6,6	2.9731	3.2872	3.042
80, Mercury	(2)(8)(18)(32)(18)2	—	▱	D^5_{3d}	2.999	—	α=70°31.7'	-46	—	6	2.999	—	3.10
GROUP IIIA IN PERIODIC SEQUENCE													
5, Boron†	(2)3	—	▯	—	17.86	8.93	10.13	Room	—	—	—	—	—
		—	△	—	8.93	—	5.06	Room	—	—	—	—	—
13, Aluminum	(2)(8)3	—	▣	O^5_h	4.0414	—	—	25	—	12	2.8577	—	2.80 to 2.858
21, Scandium	(2)(8)(9)2	α*	▣	O^5_h	4.532	—	—	Room	—	12	3.2046	—	3.20
		β	◎	D^4_{6h}	3.30	—	5.23	Room	1.585	6,6	3.23	3.30	3.27
39, Yttrium	(2)(8)(18)(9)2	—	◎	D^4_{6h}	3.663	—	5.814	Room	1.588	6,6	3.593	3.663	3.629
57, Lanthanum	(2)(8)(18)(18)(9)2	α*	◎	D^4_{6h}	3.754	—	6.063	Room	1.613	6,6	3.727	3.754	3.741
		β	▣	O^5_h	5.296	—	—	Room	—	12	3.745	—	3.745
89, Actinium	(2)(8)(18)(32)(18)(9)2	—	—	—	—	—	—	—	—	—	—	—	—
GROUP IIIB IN PERIODIC SEQUENCE													
31, Gallium	(2)(8)(18)3	—	▯	V^{18}_h	4.5167	4.5107	7.6448	Room	b/a=1:0.99868 c/a=1:1.69257	—	2.437‡	2.706‡	2.7
49, Indium	(2)(8)(18)(18)3	—	△	D^{17}_{4h}	4.585	—	4.941	22	1.078	4,8	3.24	3.37	3.14
81, Thallium	(2)(8)(18)(32)(18)3	α*	◎	D^4_{6h}	3.4496	—	5.5137	18	1.5984	6,6	3.4010	3.4496	3.42
		β	◍	O^9_h	3.874	—	—	262	—	8	3.3550	—	—

Notes: # ◍ is body-centered cubic; ▣ is face-centered cubic; ○ is hexagonal; ◎ is close packed hexagonal; ▯ is orthorhombic; ▱ is simple rhombohedral; △ is tetragonal; ▲ is face-centered tetragonal;

† Data for this element has been modified to correspond with recent publications.

‡ Complex unit cell; dimensions are for smallest interatomic distances.

* The allotrope usually existing.

Crystallography of the Chemical Elements—II

As tabulated by William Hume-Rothery in "Structure of Metals and Alloys"
Monograph No. 1, Institute of Metals, London, 1945

Modified by references to literature to May 1946 by H. C. Vacher

Atomic No. and Element	Electron Arrangement in Free Atoms	Crystal Structure: Allotrope	Type ‡	Space Group	Lattice Constants: Kx-Units: a	b	c or Axial Angle	Temperature, °C.	Axial Ratio b/a, c/a	Coordination No.	Interatomic Distances: d_1	d_2	Atomic Diameter
GROUP IVA IN PERIODIC SEQUENCE													
22, Titanium	(2)(8)(10) 2	α*	⌬	D_{6h}^4	2.953	—	4.729	Room	1.601	6,6	2.915	2.953	2.93
		β	⧈	O_h^9	3.32	—	—	900	—	8	2.875	—	—
40, Zirconium	(2)(8)(18)(10) 2	α*	⌬	D_{6h}^4	3.223	—	5.123	Room	1.589	6,6	3.166	3.223	3.19
		β	⧈	O_h^9	3.61	—	—	867	—	8	3.126	—	—
72, Hafnium	(2)(8)(18)(32)(10) 2	—	⌬	D_{6h}^4	3.200	—	5.077	Room	1.587	6,6	3.139	3.200	3.17
90, Thorium	(2)(8)(18)(32)(18)(10)(2)	—	⧈	O_h^5	5.077	—	—	Room	—	12	3.590	—	—
GROUP IVB													
6, Carbon, diamond	(2) 4	—	◇	O_h^7	3.5597	—	—	19	—	4	1.5414	—	—
Graphite		—	○	D_{6h}^4	2.4564	—	6.6906	19	2.7237	—	1.42	—	—
Graphite†		—	○	D_{3d}^5	2.456	—	10.044	19	4.251	—	—	—	—
	also reported as	□		D_{3d}^5	3.635	—	α=39.49°	—	—	—	—	—	—
14, Silicon	(2)(8) 4	—	◇	O_h^7	5.417	—	—	20	—	4	2.3458	—	—
32, Germanium	(2)(8)(18) 4	—	◇	O_h^7	5.647	—	—	Room	—	4	2.445	—	2.788
50, Tin, gray	(2)(8)(18)(18) 4	α	◇	O_h^7	6.46	—	—	18	—	—	2.797	—	3.164
white		β*	△	D_{4h}^{19}	5.8194	—	3.1753	20	0.5456	4,2	3.0161	3.1753	—
82, Lead	(2)(8)(18)(32)(18) 4	—	⧈	O_h^5	4.9395	—	—	20	—	12	3.4927	—	3.49
GROUP VA IN PERIODIC SEQUENCE													
23, Vanadium	(2)(8)(11) 2	—	⧈	O_h^9	3.0338	—	—	25	—	8	2.6273	—	2.71
41, Columbium	(2)(8)(18)(12) 1	—	⧈	O_h^9	3.2941	—	—	20	—	8	2.8528	—	2.94
73, Tantalum	(2)(8)(18)(32)(11) 2	—	⧈	O_h^9	3.2959	—	—	20	—	8	2.8543	—	2.95
91, Protoactinium	(2)(8)(18)(32)(18)(11) 2	—	—	—	—	—	—	—	—	—	—	—	—
GROUP VB													
7, Nitrogen†	(2) 5	α	□	T^4	5.66	—	—	-252	—	—	1.06	—	—
		β	○	?	4.03	—	6.59	-234	1.633	—	—	—	—
15, Phosphorus, black	(2)(8) 5	—	▯	V_h^{18}	3.31	4.38	10.50	Room	b/a=1.132 c/a=1.317	3	2.18	—	—
,yellow		*	□	?	7.17	—	—	35	—	—	—	—	—
33, Arsenic	(2)(8)(18) 5	—	▱	D_{3d}^5	4.151	—	α=53°49'	Room	—	3,3	2.508	3.146	—
51, Antimony	(2)(8)(18)(18) 5	—	▱	D_{3d}^5	4.49762	—	α=57°6'27"	25	—	3,3	2.898	3.357	3.228
83, Bismuth	(2)(8)(18)(32)(18) 5	—	▱	D_{3d}^5	4.7364	—	α=57°14'13"	25	—	3,3	3.1050	3.4740	3.64
GROUP VIA IN PERIODIC SEQUENCE													
24, Chromium	(2)(8)(13) 1	α*	⧈	O_h^9	2.878	—	—	17	—	8	2.492	—	2.57
		β	⌬	D_{6h}^4	2.717	—	4.418	Room	1.626	6,6	2.709	2.717	2.71
		γ	□	T_d^3	8.717	—	—	Room	—	—	1.043	2.043	—
42, Molybdenum†	(2)(8)(18)(13) 1	—	⧈	O_h^9	3.1403	—	—	17	—	8	2.7196	—	2.80
74, Tungsten¥	(2)(8)(18)(32)(12) 2	α*	⧈	O_h^9	3.1583	—	—	25	—	8	2.735	—	2.82
		β	□	O_h^3	5.038	—	—	20	—	—	2.519	2.816	—
92, Uranium	(2)(8)(18)(32)(13)(12)(2)	—	▯	V_h^{17}	2.852	5.865	4.945	Room	b/a=2.056 c/a=1.734	—	2.76	2.85‡	—
GROUP VIB													
8, Oxygen†	(2) 6	α	▯	?	5.50	3.82	3.44	-252	b/a=0.694 c/a=0.825	—	—	—	—
		β	□	C_{3i}^2, C_{3v}^4 or D_3^7	6.19	—	α=99.1°	-238	—	—	—	—	—
		γ	□	T_h^6	6.83	—	—	-225	—	—	—	—	—
16, Sulphur, yellow†	(2)(8) 6	α*	▯	V_h^{24}	10.48	12.92	24.55	Room	b/a=1.233 c/a=2.343	—	2.12	—	—
		β	▱	C_{2h}^6 ?	10.90	10.96	11.02 β=83°16'	103	b/a=1.101 c/a=1.006	—	—	—	—
34, Selenium†	(2)(8)(18) 6	*	○	D_3^4 or D_3^6	4.3552	—	4.9494	20	1.136	2,4	2.32	3.46	—
		α	▱	C_{2h}^5	11.50	8.98	8.977 β=90°57'	Room	—	—	—	—	—
		β	▱	C_{2h}^5	12.74	8.04	9.25 β=93°4'	Room	—	—	—	—	—
52, Tellurium†	(2)(8)(18)(18) 6	—	○	D_3^4 or D_3^6	4.4469	—	5.9149	20	1.330	2,4	2.86	3.46	—
84, Polonium†	(2)(8)(18)(32)(18) 6	—	▱	C_2^3	7.42	4.29	14.10 β=92°	Room	—	—	3.4	—	—

Notes: ‡ □ is cubic; ⧈ is body-centered cubic; ▣ is face-centered cubic; ○ is hexagonal; ⌬ is close-packed hexagonal; ◇ is cubic diamond, △ is tetragonal; ▱ is rhombohedral; ▯ is orthorhombic; ▱ is monoclinic

† Data for this element has been modified to correspond with recent publications.

‡ Complex unit cell: dimensions are for smallest interatomic distances.

* The allotrope usually existing.

¥ Usual nomenclature indicates body-centered cubic form as βW, whose constant was reported as a=5.041±0.0005 Kx at 25°C. by Rooksby, and as a=5.0408±0.0002 Kx at 18°C. by Petch.

Crystallography of the Chemical Elements—III

As tabulated by William Hume-Rothery in "Structure of Metals and Alloys"
Monograph No. 1, Institute of Metals, London, 1945

Modified by references to literature to May 1946 by H. C. Vacher

Atomic No. and Element	Electron Arrangement in Free Atoms	Crystal Structure: Allotrope	Type #	Space Group	Lattice Constants: Kx Units: a	b	c or Axial Angle	Temperature, °C.	Axial Ratio b/a, c/a	Coordination No.	Interatomic Distances: d_1	d_2	Atomic Diameter
					GROUP VII A IN PERIODIC SEQUENCE								
25, Manganese	(2)(8)(13) 2	α*	□‡	T_d^3	8.894	—	—	Room	—	—	2.24	2.38†	—
		β	□‡	O_7	6.29	—	—	Room	—	—	2.365	2.530†	—
		γ	△	D_{4h}^{17}	3.774	—	3.526	Room	0.934	8,4	2.582	2.669	—
43, Masurium	(2)(8)(18)(13)(1) 1	—	—	—	—	—	—	—	—	—	—	—	—
75, Rhenium	(2)(8)(18)(32)(13)(2) 2	—	⬡	D_{6h}^4	2.755₃	—	4.449₃	20	1.6148	6,6	2.7349	2.755₃	2.75
					GROUP VII B								
9, Fluorine	(2) 7	—	—	—	—	—	—	—	—	—	—	—	—
17, Chlorine†	(2)(8) 7	—	△	D_{4h}^{16}	8.56	—	6.12	-185	0.715	—	1.81	—	—
35, Bromine†	(2)(8)(18) 7	—	▯	V_h^{18}	4.48	6.67	8.72	-150	—	—	2.27	—	—
53, Iodine†	(2)(8)(18)(18) 7	—	▯	V_h^{18}	4.776₁	7.250₁	9.771₁	18	—	—	2.70	—	—
85, Alabamine	(2)(8)(18)(32)(18) 7	—	—	—	—	—	—	—	—	—	—	—	—
					GROUP VIII IN PERIODIC SEQUENCE								
26, Iron†	(2)(8)(14) 2	α*	◈	O_h^9	2.8607	—	—	25	—	—	2.4775	—	—
		γ	⊡	O_h^5	3.564	—	—	Room	—	—	2.52₀	—	2.52
27, Cobalt	(2)(8)(15) 2	α*	⬡	D_{6h}^4	2.50₇	—	4.07₂	Room	1.624	6,6	2.49₉	2.507	2.50
		β	⊡	O_h^5	3.54₅	—	—	Room	—	—	2.507	—	2.507
28, Nickel†	(2)(8)(16) 2	α	⬡	D_{6h}^4	2.49	—	4.08	—	1.64	6,6	2.49	2.49	2.49
		β*	⊡	O_h^5	3.5168	—	—	25	—	12	2.4868	—	2.487
44, Ruthenium	(2)(8)(18)(15)(1) 1	—	⬡	D_{6h}^4	2.6984	—	4.2730₅	20	1.5835	6,6	2.6442	2.6984	2.67
45, Rhodium	(2)(8)(18)(16)(1) 1	α	□	O_h^3 or O_h^4	9.211	—	—	Room	—	—	—	—	—
		β*	⊡	O_h^5	3.795₅	—	—	18	—	12	2.683₈	—	2.684
46, Palladium	(2)(8)(18)(18)	—	⊡	O_h^5	3.882₄	—	—	20	—	12	2.745₃	—	2.745
76, Osmium	(2)(8)(18)(32)(14) 2	—	⬡	D_{6h}^4	2.7298	—	4.3104	20	1.5790	6,6	2.6700	2.7298	2.70
77, Iridium	(2)(8)(18)(32)(15)2	—	⊡	O_h^5	3.83₁₂	—	—	18	—	12	2.709₁	—	2.709
78, Platinum	(2)(8)(18)(32)(16)2	—	⊡	O_h^5	3.915₈	—	—	20	—	12	2.768₉	—	2.769
					RARE EARTH GROUP								
58, Cerium	(2)(8)(18)(19)(9) 2	α	⬡	D_{6h}^4	3.65	—	5.91	Room	1.62	6,6	3.63	3.65	3.64
		β*	⊡	O_h^5	5.14₃	—	—	Room	—	12	3.63₇	—	3.63₇
59, Praseodymium	(2)(8)(18)(20)(9) 2	α*	⬡	D_{6h}^4	3.662	—	5.908	Room	1.613	6,6	3.633	3.662	3.65
		β	⊡	O_h^5	5.151	—	—	Room	—	12	3.642	—	3.64
60, Neodymium	(2)(8)(18)(21)(9) 2	—	⬡	D_{6h}^4	3.650	—	5.890	Room	1.613	6,6	3.621	3.650	3.63
61, Illinium	(2)(8)(18)(22)(9) 2	—	—	—	—	—	—	—	—	—	—	—	—
62, Samarium	(2)(8)(18)(23)(9) 2	—	—	—	—	—	—	—	—	—	—	—	—
63, Europium	(2)(8)(18)(24)(9) 2	—	◈	O_h^9	4.573	—	—	Room	—	8	3.960	—	4.08
64, Gadolinium	(2)(8)(18)(25)(9) 2	—	⬡	D_{6h}^4	3.622	—	5.748	Room	1.587	6,6	3.554	3.622	3.59
65, Terbium	(2)(8)(18)(26)(9) 2	—	⬡	D_{6h}^4	3.585	—	5.664	Room	1.580	6,6	3.508	3.585	3.54
66, Dysprosium	(2)(8)(18)(27)(9) 2	—	⬡	D_{6h}^4	3.578	—	5.648	Room	1.579	6,6	3.499	3.578	3.54
67, Holmium	(2)(8)(18)(28)(9) 2	—	⬡	D_{6h}^4	3.557	—	5.620	Room	1.580	6,6	3.480	3.557	3.52
68, Erbium	(2)(8)(18)(29)(9) 2	—	⬡	D_{6h}^4	3.532	—	5.589	Room	1.582	6,6	3.459	3.532	3.50
69, Thulium	(2)(8)(18)(30)(9)2	—	⬡	D_{6h}^4	3.523	—	5.564	Room	1.580	6,6	3.446	3.523	3.48
70, Ytterbium	(2)(8)(18)(31)(9) 2	—	⊡	O_h^5	5.468	—	—	Room	—	12	3.868	—	3.87
71, Lutecium	(2)(8)(18)(32)(9) 2	—	⬡	D_{6h}^4	3.509	—	5.559	Room	1.584	6,6	3.439	3.509	3.47

Notes: ‡ □ is cubic; ◈ is body-centered cubic; ⊡ is face-centered cubic; ⬡ is close-packed hexagonal; △ is tetragonal; △ is face-centered tetragonal; ▯ is orthorhombic

† Data for this element has been modified to correspond with recent publications.

* The allotrope usually existing.

‡ Complex unit cell: dimensions are for smallest interatomic distances.

‡ Approximates □ where each lattice point is a cluster of 29 atoms: 1 type X, 4 type A, 12 type D_2 and 12 type D_1. The X atoms occupy the largest volume and the D_2 the smallest. Interatomic distances of neighboring atoms are as follows:

X atoms have: 12 D_2 at 2.71; 4 A at 2.82

A atoms have: 1 X at 2.82; 3 D_1 at 2.49 and 3 at 2.96; 3 D_2 at 2.69 and 3 at 2.89

D_2 atoms have: 1 X at 2.71; 2 A at 2.69 and 1 at 2.89; 1 D_2 at 2.24 and 2 at 2.38; 1 D_1 at 2.45, 2 at 2.51 and 2 at 2.66

D_1 atoms have: 1 A at 2.49 and 1 at 2.96; 1 D_2 at 2.45, 2 at 2.51 and 2 at 2.66; 6 D_1 at 2.67

‡ Complicated structure with 20 atoms of 2 kinds in unit cell.

Each atom of the first kind has: 3 neighbors at 2.365; 3 " " 2.530; 3 " " 2.671; 3 " " 2.675

Each atom of the second kind has: 2 neighbors at 2.530; 2 neighbors at 2.615; 4 " " 2.659; 2 " " 2.671; 2 " " 2.675

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The Resistance of Metals to Scaling*

THE NATURE and extent of the attack on metals and alloys when heated in oxidizing environments are determined largely by the properties of the scale formed — its structure, chemical composition, melting and boiling points. The metal base and gas environment are generally of importance only as they affect the scale. From numerous investigations, it has been found that at high temperatures the oxidation of many metals proceeds according to a parabolic relation:

$$x^2 = kt \qquad (1)$$

where x is weight or thickness of metal consumed or formed into scale, t is time and k the parabolic rate constant. Such an equation is theoretically to be expected if oxidation proceeds by the diffusion of metal or oxygen through the scale.

The essential condition for the validity of equation (1) was shown by Pilling and Bedworth† to be the formation of a dense and adherent scale, a condition which obtains when the specific volume of the oxide is equal to or greater than that of the metal; that is, when

$$\frac{M \cdot d}{m \cdot D} \geq 1 \qquad (2)$$

where M and D are the molecular weight and density of the oxide respectively, and m and d those of the metal. Values of this ratio for the oxides formed on various metals are shown in Fig. 1. Those metals which are underlined in this diagram have been found by experiment to form adherent protective scales, increasing in weight or thickness with time according to equation (1). The almost general validity of the Pilling and Bedworth rule may be appreciated by examining this diagram.

As in other diffusional processes, the variation of oxidation rate with temperature, or the parabolic rate constant k of equation (1), may be expressed by an Arrhenius equation:

$$k = Ae^{-\frac{Q}{RT}} \qquad (3)$$

where A and Q are constants, R is the gas constant, T is absolute temperature and e the base of natural logarithms. Thus, plotting the logarithm of oxidation rate against the reciprocal of absolute temperature, the graph will be a straight line.

The weight of scale formed on those metals having oxides of smaller specific volume than that of the metal increases linearly with time. The resultant scale is porous and crumbly, and the rate of attack is controlled only by the specific reactivity of the metal and the composition of the gas atmosphere. Exceptions to the Pilling and Bedworth rule have thus far been noted only in the behavior of tungsten and molybdenum. These metals, in spite of a much higher specific volume of oxide than of metal, as shown in Fig. 1, form nonprotective oxides which increase in weight proportionally to reaction time.[2] The oxidation of molybdenum is further complicated by the high vapor pressure and relatively low melting point of the predominant oxide, MoO_3.

Still a third class of metals exists, the noble metals, having oxides with higher dissociation pressures than the partial pressure of oxygen in air at the oxidation temperature; therefore the noble metals form no superficial oxide. Thus, at low temperatures, silver forms a superficial oxide which decomposes on heating to 925° F. (300° C.), at which temperature the decomposition pressure of Ag_2O equals the partial pressure of oxygen in air. Cladding of base metals with such noble metals has been proposed as a means for their protection, but it is useful only at moderate temperatures; because of the appreciable solubility and high rate of diffusion of oxygen in such met-

*A paper prepared for the 1947 edition of "Metals Handbook".

†Reference 1. References will be found after the Appendix, on page 860.

als at elevated temperatures, oxygen penetrates to the base metal and forms a layer of oxide at the interface. For data on dissociation pressures of oxides, see the appendix and Fig. 5, page 856.

The theory of the scaling of metals which form protective oxides has been far advanced in recent years by the researches of Wagner.[3] On the basis of various experimental facts, Pfeil[4] concluded that, during the oxidation of iron, iron ions diffuse from the metal through the oxide to the oxide-gas interface and there react with oxygen. Wagner showed that in addition to negatively charged oxygen ions, both electrons and positively charged metal ions migrate through the oxide layer. The scale may be considered an electrolytic cell with its metal-base cathode and gas-atmosphere anode short-circuited by an external resistance (analogous to electron conduction through the oxide). The electromotive force of such a cell is given by the free energy of formation of the oxide. From a knowledge of the conductivity of the oxide and the relative mobilities of positive and negative ions, it is possible to calculate values of the constant k in equation (1), and these calculated values are in good agreement with experimental determinations.

It follows from this work that the lower the electrical conductivity of the oxide, the lower the rate of scaling. Since, in general, the more refractory oxides have lower electrical conductivity, those metals forming oxides of high melting point are most useful as alloying additions to confer oxidation resistance.

When temperatures and times of oxidation yield thin oxide films of thickness up to 2000 Å (0.0002 mm.), the composition, the structure, and the rate equations governing the growth of the films (as well as the methods for measuring film weight and thickness), may be quite different from the corresponding relations of the thicker films or scales discussed in this paper. Such thin films are of interest mainly in connection with corrosion studies. Qualitatively, it may be stated that the rate of film formation on metals parallels the rate of scale formation.

Li 0.57	Be 1.59									
Na 0.57	Mg 0.79	Al 1.28	Si 2.27							
K 0.45	Ca 0.65		Ti 1.95	V 3.18	Cr 1.99	Mn 1.79	Fe 1.77	Co 1.99	Ni 1.52	
Cu 1.68	Zn 1.62		Ge 1.64	As 2.15						
Rb 0.45	Sr 0.65		Zr 1.51	Cb 2.61	Mo 3.4				Pd 1.60	
Ag 1.59	Cd 1.21	In 1.23	Sn 1.32	Sb 2.35						
Cs 0.46	Ba 0.74	La 1.11	Ce 1.16		W 3.4					
			Hf 1.48	Ta 2.33						
	Hg 1.31	Tl 1.38	Pb 1.40	Bi 2.27						
			Th 1.32		U 3.05					

Fig. 1 — Ratios of Specific Volumes of Oxides and Metals, Arranged in the Periodic Sequence. The underlined metals have been found by experiment to form adherent protective seals in hot oxidizing environments

Structure of Scales — Scales generally consist of a layer-like structure, each layer comprising an oxide phase which is stable at the reaction temperature. Thus, when iron is heated in air or oxygen at atmospheric pressure and temperatures above 1000° F. (550° C.) an outside layer of Fe_2O_3, an intermediate layer of Fe_3O_4, and an inner layer of FeO appear in succession on the iron base. The surface of the iron itself is also saturated with the quantity of oxygen soluble at the oxidation temperature. The relative thickness of each layer is governed by the relative diffusivities of iron ions in each phase. Thus, since the FeO layer possesses the highest conductivity, it constitutes 85 to 90% of the total scale thickness, the Fe_3O_4 layer 10 to 15% and Fe_2O_3 layer 0.5 to 2%. When mechanically removed from the base metal, the scale separates into three sections. The outer section consists of the layers of the Fe_2O_3 and Fe_3O_4 phases; the middle section consists of the FeO phase bounded on the one side by the Fe_3O_4 layer and on the other by a plane representing the original specimen surface; while the inner section consists of the FeO phase bounded by the original surface of the iron specimen and the surface of the now unoxidized metal.

In alloys, the added element may occur in the scale in several forms, depending on its relative oxidizability with respect to the base metal. Thus, when small amounts of the additions (alloys) form refractory oxides — for example, aluminum, silicon and chromium when added to iron — the added element may occur in the inner (FeO) scale layer adjacent to the steel base, either as its own oxide or as a double oxide with FeO. The concentration of such elements in the inner layer of scale may be as high as four times their concentration in the alloy. In the two outer layers of scale, the added element may decrease to 10% of its concentration in the base metal.

In richer alloys, when such elements are increased in content, the concentration in the inner scale layer rises continuously until it consists almost entirely of the refractory oxide with a correspondingly low diffusion rate. Marked decrease in oxidation rate is to be expected only when the scale *adjacent* to the metal consists entirely of such a refractory oxide. Thus, by using a slightly oxidizing atmosphere for preheating copper containing an amount of aluminum insufficient to

retard oxidation appreciably on heating in air, Price and Thomas[5] were able to form a layer of refractory aluminum oxide on the copper which effectively stopped further scaling when the metal was reheated in air.

When metals are added which are less reactive with oxygen than the base metal, the added metal is also enriched in the scale layer adjacent to the metal surface; however, in this instance the added metal occurs as fine metallic particles embedded in the scale. Thus, on an iron-nickel alloy containing 5% nickel, metallic particles containing 30% Ni or more are found in the scale.[6] Similar precipitates occur when cobalt and copper have been added to iron. The scale structure is otherwise only slightly altered. Since *refractory* oxides do not result from such additions, little improvement in the alloy's oxidation resistance is likely to result.

The action of hot air on metals results not only in the formation of external scales, but oxygen also diffuses into the metal base resulting in "internal oxidation". Steels containing chromium, aluminum or silicon form internal oxides of these elements (or their double oxides with FeO) embedded in the surface of the metal, often at grain boundaries. One important result is that subsequent pickling for complete removal of scale is very difficult.[7] In steels containing copper, the diffusion of oxygen into the surface, forming oxides with iron, leads to the precipitation of metallic copper at the grain boundaries; in the presence of excessive amounts of sulphur in the steel, such liberation of copper may cause surface defects during hot working.[8] Penetration of oxygen into steel is considerably increased by additions of nickel; 6% Ni increases the depth of internal oxidation about four times, presumably as a result of a higher solubility of oxygen in steels containing nickel. Cobalt and molybdenum additions behave similarly. The presence of such oxidized zones not only leads to difficulties in pickling but also may cause surface cracks during hot working.

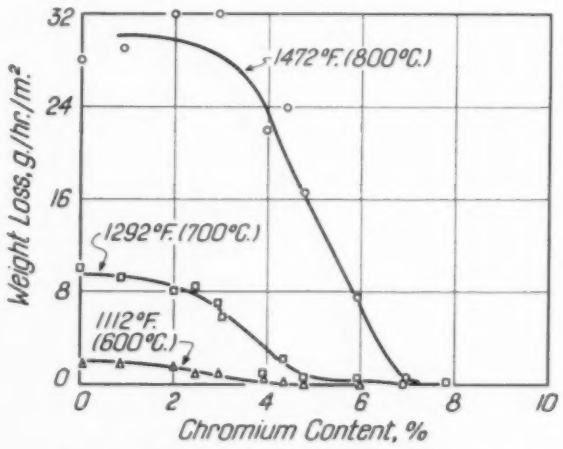


Fig. 2 — Effect of Chromium Content on the Scaling of Steel Containing 0.15% C, 0.7 to 0.9% Si, After 120 Hr. in Air (Houdremont)

Determination of Oxidation Resistance — A number of methods are available for measuring the resistance of materials to attack by oxidizing atmospheres; the choice of method will depend on the particular application of the material and its physical form. Methods which have been used are:

1. Determination of the increase in weight of specimens after a given interval of exposure. Such a method is particularly applicable for the continuous measurement of the course of oxidation, and enables the experimenter to compare materials which are to be subjected to attack at a constant temperature.

2. Determination of the decrease in weight after removing the external scale. This method is particularly useful in evaluating the effect of various furnace atmospheres on the rate of metal loss, or damage to surface finish and on the ease of pickling.

3. Measurement of the amount of gas consumed in the oxidation reaction. This, like Method 1, is particularly applicable to the continuous determination of the rate of attack.

4. Determination of the time necessary for the destruction of a given size of material. This has been extensively used as a test for heater element wire. Bash and Harsch[9] devised a method of testing which, with slight modification, has been adopted in an A.S.T.M. specification B76-39 as a life test for electrical heating alloys. Briefly, a 12-in. length of No. 20 or No. 22 gage wire is suspended between a fixed upper clamp and a mercury cup. Current through the wire is so adjusted as to yield, depending on the alloy composition, a temperature of 2050 to 2150° F., as measured by an optical pyrometer. The time required to burn out the wire with the current, 2 min. on and 2 min. off, is accepted as the life of the material. Wire life is comparatively unaffected by variation in size for diameters larger than No. 24 American wire gage. Of considerable effect are the actual and relative durations of heating and cooling. A time cycle of 2 min. on, 2 min. off, was found to be most injurious.

Rate of Oxidation of Alloys — The principal criterion for an oxidation resistant alloy is its ability to form an oxide scale of low electrical conductivity, which indicates a low rate of metal ion diffusion, as outlined above. Equally important

Fig. 4 (Right) — Constituents of Scale Layers in Iron-Nickel-Chromium Alloys at 1830° F.[14, 7]

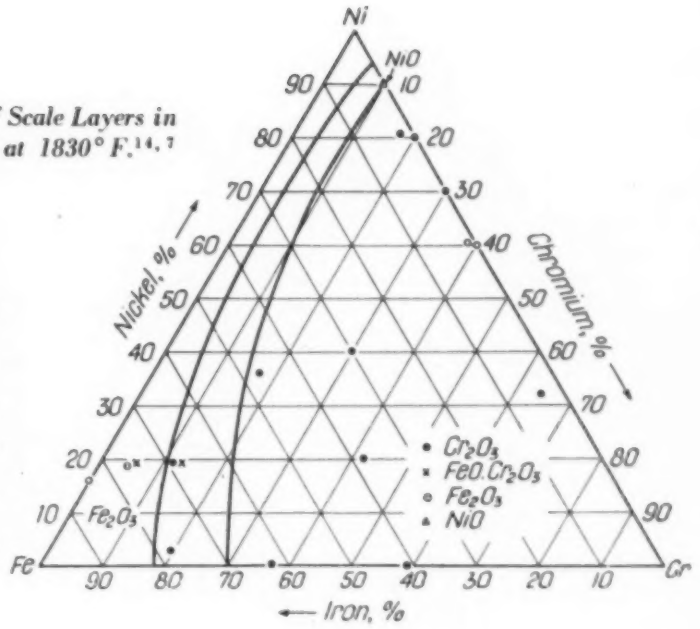
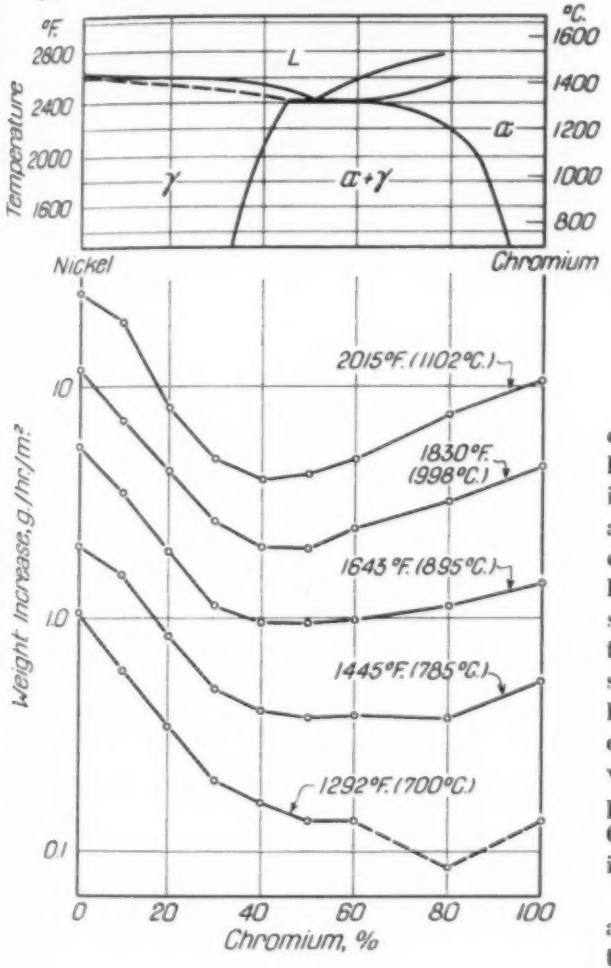


Fig. 3 — Relation Between Scaling and Phase Diagram of Chromium-Nickel Alloys (Matsunaga)



for high temperature resistance is the melting point of the oxide. In general, the higher the melting point of an oxide, the lower its conductivity. Presence of alloy elements which form low melting eutectics or compounds with other constituents of the scale must be avoided, since molten scales give no protection. Thus the presence of 0.04% boron in a 30% chromium steel completely destroys scaling resistance at temperatures of 2200° F. (1200° C.).[10] Likewise steels with more than 5% silicon are useless above 2200° F. because of the FeO-SiO_2 eutectic, melting at 2250° F. (1240° C.). In the following paragraphs it may therefore be noted that those alloys which form refractory oxides are most resistant to oxidation.

1. **Chromium-Iron Alloys** — The most important component of heat resistant alloys is chromium, both because it forms a highly refractory oxide and because its alloys with nickel and iron or both are workable even at high chromium contents. The effect of increasing chromium content in a 0.15% C, 0.7 to 0.9% Si steel, heated in air for 120 hr. at various temperatures, is shown in Fig. 2. It may be noted that, at each temperature, with increasing chromium content the amount of scale decreases continuously to a low value. After this low value has been reached further chromium additions cause little improvement. The chromium content at which a low rate of scaling is obtained denotes the composition at which the scale consists entirely of refractory Cr_2O_3; it may be noted that the chromium required increases with increasing temperature.

Curves of the type shown in Fig. 2 are general for all alloy additions conferring oxidation resistance. For temperatures higher than 1800° F. (1000° C.), alloys with 30% chromium or more are necessary. Oxidation characteristics of iron-chromium alloys may be improved still further by additions of aluminum or silicon in amounts over 2%.[12]

2. **Chromium-Nickel Alloys** — It may be noted from Fig. 3 that improvement in the oxidation resistance of nickel is concurrent with chromium additions up to its solubility limit. Since technical chromium-nickel alloys nearly always contain manganese and silicon, which decrease the solubility of chromium in nickel, such alloys are limited to a maximum of 25% chromium.

Carbon, by combining with chromium to form insoluble carbides, decreases the scaling resistance of nickel-chromium alloys; the life of an 80% Ni, 20% Cr alloy is reduced one-half by the presence of 0.30% C.[13] Manganese also causes a slight increase in scaling rate, while silicon and aluminum, even in amounts insufficient to reduce the workability appreciably, improve oxidation

resistance. Tungsten and molybdenum, which may be added to improve high temperature strength, have little effect on the scaling resistance.[14]

3. **Nickel-Chromium-Iron Alloys** — Still more important than the iron-chromium alloys as heat resistant materials are the nickel-chromium-iron alloys. From the point of view of oxidation resistance, the nickel in these alloys may be considered as a diluent with little effect on the rate of scaling, as shown in Fig. 4, page 853, wherein the principal constituents of the scale formed on various alloys at 1830° F. (1000° C.) are plotted. The lines divide the composition range into three regions; the one at right (high chromium contents) denotes alloys having, when oxidized, an increase in weight of less than 0.001 g./cm.^{2} in 7.5 hr. at 1000° C.; the increase in weight at low chromium contents is more than 0.01 g./cm.^{2}; and the increase in weight in the intermediate region is less than 0.01 g./cm.^{2} In the region of low weight increase the scales which form are predominantly Cr_2O_3, and scales containing NiO or Fe_2O_3 form in the region of high weight increase. Nickel is only slightly more effective than iron in suppressing oxidation; chromium is mainly responsible for reducing the scaling attack.

4. **Aluminum-Iron Alloys** — Aluminum is the most effective addition for suppressing the scaling of iron. Ziegler[16] showed that an 8% aluminum alloy has the same oxidation resistance as an 80% Ni, 20% Cr alloy. If the scaling rate of aluminum-iron alloys is plotted against aluminum content, curves will be drawn similar to those shown in Fig. 2 for chromium-iron; larger concentrations of aluminum are required as the reaction temperature goes up. Low rates of oxidation are obtained only when a white Al_2O_3 scale forms over the surface of the alloy. These alloys find only limited application; they are difficult to fabricate and the Al_2O_3 scale is sensitive to damage.

5. **Aluminum-Chromium-Iron Alloys** — Chromium is added to aluminum-iron alloys to improve their workability. Even in such alloys, aluminum is the most effective agent for restraining oxidation, minimum attack being noted when

Table I — Maximum Temperature of Stability of Various Alloys to Oxidizing Atmospheres[24]

Material	Composition	Stable in Air to Indicated Temperature	
		Fahrenheit	Centigrade
Copper		840	450
Iron		925	500
Brass	70% Cu, 30% Zn	1290	700
Nickel		1465	800
Chromium		1650	900
Chromium-iron alloys	4 to 6% Cr, 0.1 to 0.2% C, 0.5% Mn, 0.5% Si, rest Fe	1200	650
	8 to 10% Cr, 0.15% C max., 0.5% Mn, 0.5% Si, rest Fe	1375	750
	12 to 14% Cr, 0.10% C max., 0.5% Mn, 0.5% Si, rest Fe	1375 to 1475	750 to 8
	16 to 18% Cr, 0.10% C, 0.5% Mn, 0.5% Si, rest Fe	1550 to 1650	850 to 9
	25 to 30% Cr, 0.10% C, 0.5% Mn, 0.5% Si, rest Fe	1900 to 2000	1050 to 11
Nickel-chromium-iron alloys	17 to 19% Cr, 8 to 10% Ni, 0.5% Mn, 0.5% Si, 0.1% C, rest Fe	1550 to 1650	850 to 9
	17 to 19% Cr, 25 to 26% Ni, 0.5% Mn, 3.0% Si max., 0.2% C max., rest Fe	1900 to 2000	1050 to 11
	22 to 28% Cr, 12 to 16% Ni, 0.5% Mn, 0.5% Si, 0.15% C max., rest Fe	1825	1000
	24 to 26% Cr, 19 to 21% Ni, 0.75% Mn, 1.0% Si, 0.15% C max., rest Fe	1900 to 2000	1050 to 11
	15 to 20% Cr, 30 to 35% Ni, 0.5 to 1.0% Mn, 1 to 2% Si, 0.15% C max., rest Fe	1900 to 2000	1050 to 11
	14 to 18% Cr, 60 to 66% Ni, 1 to 2% Mn, 1.5 to 2% Si, 0.1 to 0.5% C, rest Fe	1825 to 2000	1000 to 11
	12 to 20% Cr, 70 to 80% Ni, 2% Mn, 2% Si, 0.15% C, rest Fe	2000 to 2100	1100 to 11
Chromium-nickel alloy	19 to 20% Cr, 77 to 79% Ni, 2.5% Mn, 0.5% Si, 0.25% C max., rest Fe	2100	1150
Chromium-iron alloys with aluminum	5 to 6.3% Cr, 0.6 to 0.8% Al, 0.45% Mn, 0.5% Si, 0.10% C, rest Fe	1465	800
	6.5 to 8.5% Cr, 1.2 to 2.0% Al, 0.45% Mn, 1.0% Si, 0.10% C, rest Fe	1650	900
	12 to 15% Cr, 2.5 to 3.5% Al, 0.5% Mn, 0.5 to 1.0% Si, 0.12% C, rest Fe	1650 to 1825	900 to 1
	18 to 20% Cr, 3 to 4% Al, 0.5% Mn, 0.5 to 1.0% Si, 0.12% C, rest Fe	2175	1200
	20 to 22% Cr, 3 to 5% Al, 0.5 to 1.5% Mn, 0.5% Si, 0.10% C, rest Fe	2275 to 2360	1250 to 13
	20% Cr, 5% Al, 1.5 to 3.0% Co, rest Fe	2000 to 2360	1150 to 13
	30% Cr, 5% Al, 0.5% Mn, 0.5% Si, 0.1% C, rest Fe	about 2425	about 133

the principal scale constituent is Al_2O_3.[6] The optimum composition of such alloys lies in the range 20 to 30% chromium and 3 to 8% aluminum.

6. **Silicon-Iron and Silicon-Chromium-Iron Alloys** — Silicon behaves like aluminum in reducing the scaling of iron, although it is somewhat less effective. Because of the low melting point of the FeO-SiO_2 eutectic, these alloys are not considered heat resistant. Alloys containing 12 to 30% chromium and 5 to 10% silicon are quite scale resistant but, like the aluminum-chromium-iron alloys, they are difficult to work.

7. **Copper-Base Alloys** — Oxidation resistant copper-base alloys are obtainable only when the low melting, highly conductive copper oxide scale is replaced by a refractory oxide scale. Thus, Dunn[17] showed that zinc-copper alloys are appreciably more resistant than copper only with zinc contents greater than 25% when a ZnO scale forms. Frohlich[18] found that aluminum, beryllium, magnesium and silicon additions afford real protection to copper; zinc and tin somewhat less; while iron, nickel, manganese, calcium, chromium and other elements afford none. The addition of several per cent of beryllium, silicon (or both) to "constantan" (55% Cu, 45% Ni) increases the alloy's maximum temperature of use from 1100 to 1475° F. (600 to 800° C.).[19]

Effect of Minor Impurities on Oxidation Resistance — Smithells, Williams and Grimwood[20] found that the purity of the initial materials had an appreciable effect on the life of nickel-chromium alloys. Alloys made of electrolytic chromium failed much more quickly than did those made of chromium reduced by the thermit reaction ($Cr_2O_3+2Al=2Cr+Al_2O_3$). This effect was further investigated by Hessenbruch[21] who found that, by suitable additions, the life of various heat resistant alloys could be prolonged as much as 10 times. Additions of calcium, thorium and, notably, cerium in amounts less than 0.5% improved scaling resistance to a degree out of all proportion to the amounts of added element. Such improvement was found to be general with additions of the alkali earths and rare earth elements.

Hessenbruch offered a tentative explanation of these results, based on the observation that those elements which, when present in small amounts, prolonged the life of nickel-base alloys had atomic volumes greater than that of nickel oxide, whereas those elements which had smaller atomic volumes had no effect. Presumably such minor impurities are to be considered as obstacles to the passage of nickel ions through the scale.

Influence of Gas Atmosphere — In any discussion of the oxidation resistance of metals, the effect of gas atmosphere must be considered, since the composition, pressure, and rate of flow of the atmosphere may affect the structure, composition and adherence of the oxide scale. Thus, steel is oxidized at an increasing rate by atmospheres of carbon dioxide, dry air, oxygen and steam, respectively. To be stable in steam at 925° F. (500° C.) a steel must be resistant in air at 1200° F. (650° C.), and to withstand steam at 1750° F. (950° C.) must withstand air at 2200° F. (1200° C.).

The oxidation of mild steel in air was shown by Hatfield[22] to be trebled by the addition of 5% SO_2 and 5% H_2O to the atmosphere, and doubled by 5% CO_2 and 5% H_2O. Likewise the oxidation rate of 18-8 in air is increased 10 times by the latter atmosphere, eight times by the former and seven times by 5% H_2O. Nickel and alloys containing nickel are seriously embrittled by atmospheres containing sulphur compounds, and the copper alloys are rapidly attacked by atmospheres containing chlorine or its compounds.

Griffiths[23] found that the adherence of scale to steel is markedly affected by gas composition and rate of heating and cooling. The factors controlling the adherence of scales to metal surfaces have been only sparingly investigated.

Oxidation Stability of Alloys — Because of the marked effect of small amounts of impurities in the gas atmosphere and in the base metal, and because of the sensitivity of scaling rate to factors such as heating cycles and rate of heating, it is impossible to state with certainty the range of stability of materials in oxidizing atmospheres. Any listing of alloys in their order of merit with respect to scaling must therefore be considered as comparative only for given atmospheres, heating and cooling cycles and other test conditions. The temperature of stability in Table I is chosen as that temperature below which scaling losses are less than 0.0002 to 0.0004 g./cm.²/hr.

Appendix—Dissociation Pressures of Oxides Formed on Various Solid Metals

A factor of prime importance in determining the oxidation behavior of metals at elevated temperatures in air and in industrial atmospheres is the dissociation pressure of the metal oxide which is formed on heating. The thermodynamic data necessary for the calculation of this property for most of the common metals are available and have been compiled in a series of papers by K. K. Kelley, issued by the U. S. Bureau of Mines (Bulletins 371, 394 and 434). From the data so available the dissociation pressures have been calculated as a function of temperature and are presented in the accompanying Fig. 5, page 856.

For the calculation it is necessary to know the specific heats and

entropies of each of the components in the reaction as well as the heat of reaction at a given temperature. The change in specific heat (ΔC_p) may be expressed by the equation

$$\Delta C_p = \Delta A + \Delta b T - \Delta C T^{-2}$$

where ΔA, Δb, and ΔC are constants and T is absolute temperature. The heat of reaction (ΔH) is then

$$\Delta H = \Delta H_o + \Delta A T + \frac{\Delta b}{2} T^2 + \Delta C T^{-1}$$

where ΔH_o is a constant. The free energy change (ΔF) may then be expressed by the following:

$$\Delta F = \Delta H_o - \Delta A T \cdot \ln T - \frac{\Delta b}{2} T^2 + \frac{\Delta c}{2} T^{-1} + IT$$

$$\Delta F = \Delta H - T\Delta S = \Delta H_o + \Delta A T + \frac{\Delta b}{2} T^2 + \Delta C T^{-1} - T\Delta S$$

in which I is a constant, and ΔS the entropy change. Then

$$\Delta F = -RT \cdot \ln K$$

with R the gas constant and K the equilibrium constant of the oxidation reaction.

The method of calculation is illustrated for the reaction

$$2Al + \frac{3}{2} O_2 = Al_2O_3 \text{ at } 20^\circ \text{ C. } (293^\circ \text{ absolute})$$

$$\Delta C_p = C_p(Al_2O_3) - 2C_p(Al) - \frac{3}{2} C_p(O_2)$$

From Kelley's publications we select the constants for the indicated substances and substitute:

$$\Delta C_p = 0.08 + 2.124 \times 10^{-3} T - 2.41 \times 10^5 T^{-2}$$

$$\Delta S_{293} = S_{Al_2O_3 \text{ at } 293} - 2S_{Al \text{ at } 293} - \frac{3}{2} S_{O_2 \text{ at } 293} = -74.59$$

Knowing the heat of reaction at $T = 293^\circ$ as $-393{,}300$ cal., one may calculate ΔH_o to be $-394{,}238$ and I to be 77,133, and thus obtain the relation for the free energy change:

$$\Delta F = -394{,}238 - 0.08T \cdot \ln T - 1.062 \times 10^{-3} T^2 + 1.205 \cdot 10^5 T^{-1} + 77.133T$$

Since the equilibrium constant K of this reaction equals $\frac{C_{Al_2O_3}}{C^2_{Al} \cdot p^{3/2}_{O_2}}$

we derive $\log K = -\frac{3}{2} \log p_{O_2}$

At 100° K $\Delta F = -395{,}370$

and since $\Delta F = -RT \cdot \ln K$

$\log K = +866$

and $\log p_{O_2} = -577.3$

The curves shown in Fig. 5 were computed in this way and plotted.

Since the data for the solid metals were used, the curves are valid only up to the melting point of the metal (shown as open circles). However, since little change in the curves would be introduced by considering the change in state of the metal, and since adequate data are not available for making this calculation, the curves were extended to the boiling point of the metal, or the melting or decomposition temperature of the oxide, whichever was lower.

Also included in the figure are curves for the oxygen partial pressures in equilibrium with CO-CO_2 and H_2-H_2O mixtures typical of industrial furnace atmospheres such as "Endogas", "Exogas", and "Ammogas". Since for these gas mixtures

$$\log p_{O_2} = 2\log K + 2\log \frac{P_{H_2O}}{P_{H_2}}$$

$$\text{or } 2\log K + 2\log \frac{P_{CO_2}}{P_{CO}},$$

the oxygen partial pressures for atmospheres of differing component ratios may be derived from the depicted curves by shifting the curves parallel to the ordinate an amount equal to twice the logarithm of the ratio of desired to known. Thus, the oxygen partial

(Continued on page 860)

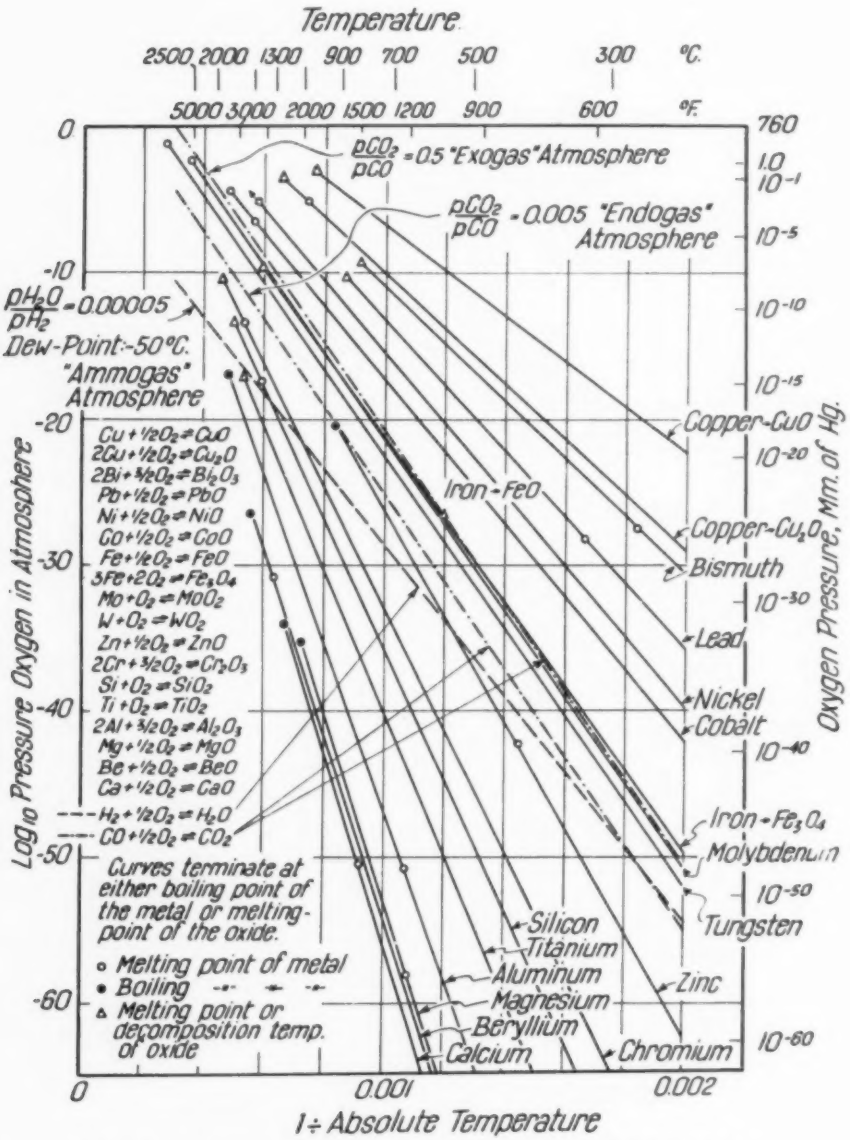


Fig. 5 — Curves of Dissociation Pressures of Metal Oxides Formed at Various Temperatures on Several Common Metals

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the Results: The tool maker, using the Matched Set Method, went to Carpenter *Hampden* (Oil-Wear) for greater wear resistance. The new *Hampden* punch eliminated *11 hours* of machine down-time each week and produced *550,000 additional* diaphragms per grind!

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Resistance to Scaling

(Continued from page 856)

pressure for a gas atmosphere 100 times richer in CO_2 than the ratio $\frac{P_{CO_2}}{P_{CO}}$ of 0.005 lies 4 logarithmic units above the latter.

For any given atmosphere, the metal will not oxidize if the dissociation pressure of its oxide is greater than the oxygen partial pressure of the gas atmosphere. Thus, zinc will not oxidize in "Ammogas" (of dew point of −58° F. or −50° C.) when temperatures are above 1000° F. (540° C.), whereas it will oxidize below this temperature.

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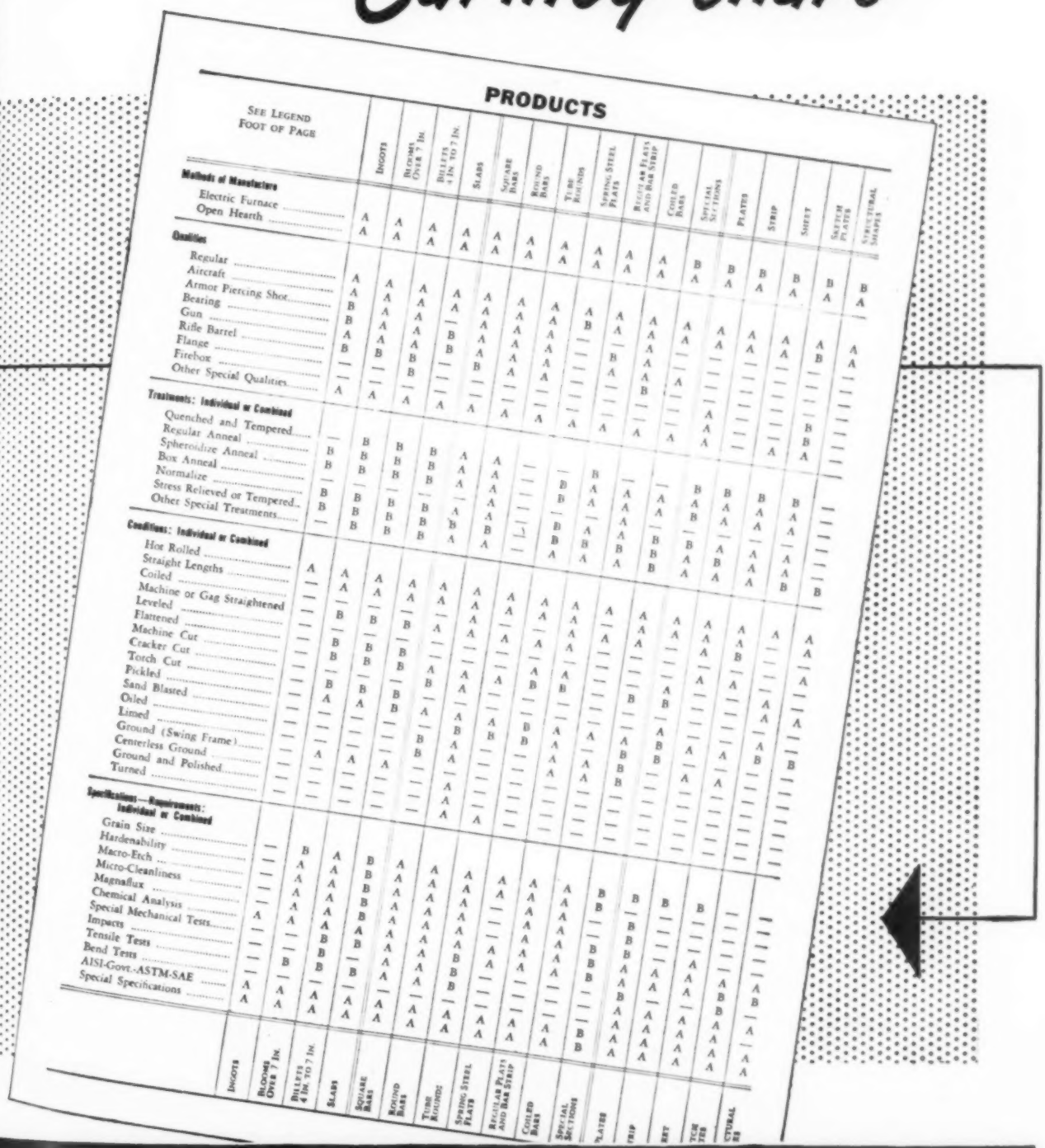
in alloy steel—

you'll find on this Carilloy chart



STATES STEEL

Wrought Aluminum Alloys

Compositions, Properties, and Designations of American Commercial Alloys

Compiled by H. S. Jerabek, University of Minnesota, July 1946, from handbooks and specifications of the principal manufacturers, the American Society for Testing Materials, and the Society of Automotive Engineers.

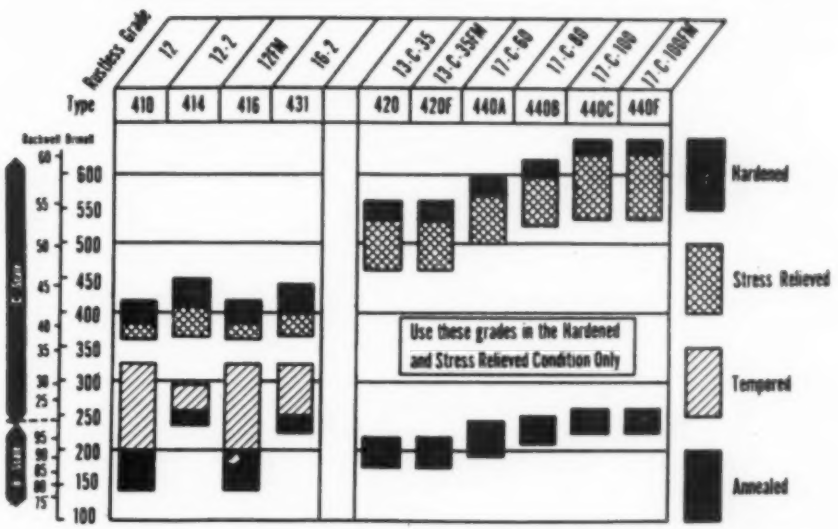
Designations					Composition Aluminum = Balance					Form Tested	Tensile Strength (c)		Yield Strength (c)		Elongation, % in 2 In.		Brinell Hardness	Shear Strength (c)	Endurance Limit (c)(d)	Cold Bend Test (e)	Corrosion Resistance in NaCl (f)	Uses and Characteristics
S.A.E. No.	A.S.T.M. Spec No.	A.S.T.M. Alloy No.	Alcoa No. (a)	Reynolds (b)	Cu	Si	Mn	Mg	Others		Ave.	Min.	Ave.	Min.	Ave.	Min.						
										WORK HARDENING ALLOYS—NOT HEAT TREATABLE (g)												
25	B25	A2	2S-O	2S					99 Al	1/16" Sheet	13 (15 max.)		5		35	30	23	9.5	5	A	A	Commercial Al; good forming properties.
	B25	A2	2S-1/2H							-"- -"-	17	18	14		9	5	32	11	7	B	A	Good corrosion resistance, low yield strength
	B25	A2	2S-H							-"- -"-	24	22	21		5	4	44	13	8.5	F	A	Cooking utensils; sheet and tubing.
29	B79	M1	3S-O	3S			1.2			-"- -"-	16 (19 max.)		6		30	25	28	11	7	A	A	Similar to 2S
	B79	M1	3S-1/2H							-"- -"-	21	19.5	18		8	5	40	14	9	C	A	Slightly stronger and less ductile.
	B79	M1	3S-H							-"- -"-	29	27	25		4	4	55	16	10	G	A	Cooking utensils; sheet metal work.
201	B109	MR1	52S-O	52S				2.5	0.25 Cr	-"- -"-	29 (31 max.)		14		25	20	45	18	17	A	A	Strongest work hardening alloy.
	B109	MR1	52S-1/2H							-"- -"-	37	34	29		10	6	67	21	18	D	A	High yield strength and fatigue limit.
	B109	MR1	52S-H							-"- -"-	41	39	36		7	4	85	24	19	G	A	Highly stressed sheet metal products.
										PRECIPITATION HARDENING ALLOYS—HEAT TREATABLE (h)												
26	B78	CM21	17S-O	17S	4		0.5	0.5		1/16" Sheet	26 (35 max.)		10		20	12	45	18	11	B	E	Duralumin. Original strong alloy.
	B78	CM21	17S-T							-"- -"-	62	58	40	34	20	18	105	38	18	H	D	Hardened by quenching and aging.
	B89	CM21	17S-T							1/2" Rod Extruded		55		32		12					D	Being replaced somewhat by stronger alloys:
			17S-T							Forgings	60	55	30	30	16	16	100	38	18		D	24S, 75S and R303.
24			24S-O	24S	4.6		0.6	1.5		1/16" Sheet	27 (36 max.)		11		19	12	42	18	12	B	E	Stronger than 17S
			24S-T							-"- -"-	68	64	46	42	19	17	120	41	18	J	D	Used widely in aircraft construction.
			24S-RT							-"- -"-	73	69	57	52	13	12	130	42		K	D	More difficult to form than 17S
240			Alclad 24S-T	Pure Clad 24S						-"- -"-	64	59	43	39	18	15		40		J	A	Alclad has improved corrosion resistance.
			Alclad 24S-T86							-"- -"-	70	66	66	62	6	3					A	T86, cold worked before aging.
			24S-T							1/2" Ext. Shapes		60		44		12					D	Standard alloy for thin extrusions.
260			14S-O		4.4	0.8	0.8	0.4		1/2" Ext. Shapes	27 (35 max.)		14		18	12	45	18	11			Strong alloy for extruded shapes.
			14S-W							-"- -"- -"-	56	50	40	32	25	12	100	34	18			Will not age harden at room temperature.
			14S-T							-"- -"- -"-	70	65	60	55	13	7	135	42	18		D	
			14S-T	14S						Forgings		65		55		10	125	42	18		D	Strongest forging alloy
			Alclad 14S-T							1/16" Sheet	65	64	58	57	9	8		41			A	Higher yield strength than Alclad 24S
				R301-T	4.5	1.0	0.8	0.4		-"- -"-	68	63	60	56	10	7		43	12			Clad with heat treatable alloy. (i)
			75S-O		1.6	5.6 Zn	0.2	2.5	0.3 Cr	1/16" Sheet	33 (40 max.)		15		17	10					E	New alloy of highest strength
			75S-T							-"- -"-	82	77	72	66	11	8	150	47	22.5		D	Lower ductility than 24S.
			Alclad 75S-T							-"- -"-	76	72	67	62	11	8		46			A	Strongest Alclad product
			75S-T							1/2" Ext. Shapes		80		70		6						Strongest alloy for extrusions.
				R303-T275	1.3	6.5 Zn		2.5	0.3 Cr	-"- -"- -"-	85	80	77	72	9	7		48	22.5			High strength alloy for sheet, rod, forgings.
281			61S-W	R361	0.25	0.6		1.0	0.25 Cr	1/2" Ext. Shapes	35	30	21	16	22	16	65	24	13.5	E	C	Good forming properties; high yield str.
			61S-T							-"- -"- -"-	45	42	40	35	12	10	95	30	13.5	F	C	Will not age harden at room temperature.
282			53S-W	R353		0.7		1.3	0.25 Cr	1/2" Rod Extruded	33	25	20	14	22	16	65	20	13	F	B	Good forming properties and corrosion
			53S-T							-"- -"- -"-	39	32	33	25	14	14	80	24	13	G	B	resistance.
			53S-T							Forgings		36		30		14	75	24	13			
201			A51S-T	A51S		1.0		0.6	0.25 Cr	Forgings		44		34		12	90	32	11		C	For intricate forgings.
27			25S-T	25S	4.5	0.8	0.8			-"-		55		30		16	100	35	18		E	Good forgeability. Lower cost.
270			18S-T	18S	4			0.5	2 Ni	-"-		55		40		10	100	39	17		E	Strong at elevated temp.; forged pistons.
290			32S-T	32S	0.9	12.5		1.0	0.9 Ni	-"-		52		40		5	115	38	18		C	Forged aircraft pistons. "Low-X".
			11S-T3		5.5				(0.5 Bi) 0.5 Pb	1/2" Rod	53	45	47	38	15	10	95	30	12.5		E	Free cutting, screw machine products.
				R317-T	4	(0.5 Bi)	0.7	0.5	0.5 Pb	-"- -"-		55		32		12	105					-"- -"- -"- -"- -"-

(a) Aluminum Co. of America alloy numbers and heat treatment designations: O = annealed, W = as quenched, T = quenched and aged, H = cold rolled to hard temper, 1/2H = half hard temper, R = cold rolled after heat treatment, S = wrought alloy.
(b) Reynolds Metals Company designations.
(c) In thousands of pounds per square inch. Yield strength taken at 0.2% permanent set.
(d) 500 million cycles in reverse bending.
(e) Relative forming properties in cold bending; A = best
(f) Relative resistance to salt water corrosion; A = best
(g) Can be hardened by cold work only.
(h) -"- -"- -"- -"- heat treatment.
(i) Cladding alloy: 1.0 Mg, 0.7 Si, 0.5 Mn.

RUSTLESS DATA SHEET NO. 8

Corrosion Resistance Plus Hardness By Heat Treatment

One of the Many Combinations of Properties Offered by Stainless Steels



THERE are 29 standard grades of stainless steels... some are hardenable by heat treatment... some contain nickel ...all contain chromium. This variation in composition and response to heat treatment divides them naturally into three distinct groups.

Group I ... Chromium. Hardenable by heat-treatment.

Group II ... Chromium. Hardenable slightly by cold work only.

Group III ... Chromium-nickel. Hardenable only by cold work.

Stainless steels included in Group I are the only grades which respond to hardening by quenching, stress relieving and tempering operations in a manner similar to carbon and low alloy steels. The most commonly used Group I grades and their response to heat treatment is shown on the above chart. Highest hardness is developed with Type 440C which is used for applications requiring wear resistance, such as balls and ball bearing races. Type 440F, the free-machining counterpart of Type 440C, is used for valves and other parts requiring extreme hardness plus good machinability. Types 420, 440A and 440B develop hardness values ranging from a minimum of 450 Brinell for Type 420 to a maximum of 600 Brinell for Type 440B. They are used for products such as surgical instruments, valve seats, cams and carving knives. Type 420F is the free-machining counterpart of Type 420. Types 410, 414, 431 contain less carbon, develop slightly less hardness, but provide greater protection against corrosion, particularly Type 431 which has the best corrosion resistance of any in this group. In general, corrosion resistance increases with the chromium content and decreases as carbon content rises. The lower carbon grades are used extensively for turbine blades, cold-headed screws, bolts, pistons, pump rods and many other products. Type 416 is the free-machining counterpart of Type 410. It is widely used for high speed machining operations on automatic equipment.

Hardening the Group I alloys is accomplished by heating above the critical or transformation temperature and rapidly cooling in air or oil. Water quenching is not a good practice and is likely to produce quench cracks, especially with the high carbon grades. Hardening should always be immediately followed by a low temperature treatment (300°-700°F.) to relieve stresses developed in quenching, particularly the high carbon grades. A wide range of tensile and hardness properties can be secured by tempering Types 410, 414, 416 and 431. The higher carbon types should be used only in the hardened and stress relieved conditions because of the adverse effect tempering has on their corrosion resistance. When you want to know more about the heat-treatment of stainless steels, consult Rustless Division of ARMCO.

For complete information on the heat treatment of all stainless grades, request a copy of Rustless' comprehensive and widely read 58 page book "Heat Treatment of Stainless Steels". If you merely need handy reference charts on some particular grade – for use under your desk top or in the shop—send for copies of Rustless' "Heat Treatment Data Sheets".

Rustless

DIVISION OF ARMCO

RUSTLESS IRON AND STEEL DIVISION

THE AMERICAN ROLLING MILL COMPANY

Baltimore 13, Maryland

STAINLESS STEEL SPECIALISTS

Aluminum Casting Alloys

Compositions, Properties, and Designations of American Commercial Alloys

Complied by H. S. Jerabek, University of Minnesota, July 1946, from handbooks and specifications of the principal manufacturers, the American Society for Testing Materials, and the Society of Automotive Engineers.

Designations				Composition Aluminum - Balance						Form Tested (b) (c)	Tensile Strength (d)		Yield(d) Strength	Elongation, % in 2 In.		Brinell Hardness	Shear Strength(d)	Endurance Limit(d)(e)	Relative Impact Toughness	Corrosion (g)	Alcoa No.(a)	Uses and Characteristics
S.A.E. No.	A.S.T.M. Spec. No.	A.S.T.M. Alloy No.	Alcoa No. (a)	Cu	Si	Mg	Zn	Max. Fe	Others		Ave.	Min.	Ave.	Ave.	Min.							
										SAND CASTINGS											
33	B26	CS22	113	7.0	2.0		1.7	1.4		As Cast	24	19	15	1.5		70	20	9		D	113	General casting alloy; not heat treated.
			212	8.0	1.2					As Cast	23	19	14	2		65	20	8	0.6	D	212	-"- -"- -"- -"- -"- -"-
			112	7.0			1.7			As Cast	24	19	15	1.5		70	20	9	0.6	D	112	-"- -"- -"- -"- -"- -"-
			645	2.7			10.5	2.0		As Cast	29	25	17	4	2.5	70	22	7.5	2.0	D	645	Toughness drops on aging at room temp.
310	B26	ZG41				0.6	5.5	(0.5 Cr)	0.2 Ti	As Cast; Aged		30	25		3					C		High strength after aging at room temp.
35	B26	S1,S2	43		5.0			0.8		As Cast	19	17	9	6	3	40	14	6.5	1	B	43	Thin walled, pressure tight castings.
			45		10.0					As Cast	21	18	10	4.5	1.5	45	16	6		B	45	Excellent casting properties.
37					12.0			0.8	Trace Na	As Cast "Modified"	26	24	11	8	5	50	18	6	3	B		Alpax or Silumin. High strength "as cast".
326			108	4.0	3.0			1.2		As Cast	21	19	14	2.5	1.5	55	20	8			108	Used mostly "as cast" but responds to H.T.
320	B26	G1	214			3.8		0.6		As Cast	25	22	12	9	6	50	20	5.5	3.8	A	214	Good corr. resistance and toughness.
38	B26	C1	195-T4	4.5	0.8			1.0		Soln. H.T. (b)	32	29	16	8.5	6	60	24	6	2.8	C	195-T4	Heat treatable. High strength, toughness.
38	B26	C1	195-T62							Soln. H.T.; Aged (C)	40	36	30	2		95	31	7	1.3	C	195-T62	Fully hardened alloy has low ductility.
325	B26	C2		3.8	2.0			1.2		Soln. H.T. (b)		27	16		3					C		High strength and ductility.
322	B26	SC21	355-T6	1.3	5.0	0.5		0.6		Soln. H.T.; Aged (C)	35	32	25	2.5	2	80	30	8.5	1.1	C	355-T6	Liquid cooled cylinder heads.
322	B26	SC21	355-T61							Soln. H.T.; Aged (C)	39	36	35	1		90	32		0.8	C	355-T61	Good strength at elevated temperatures.
323	B26	SG1	356-T6		7.0	0.3		0.6		Soln. H.T.; Aged (C)	33	30	24	4	3	70	27	8	1.0	A	356-T6	Intricate heat treated castings.
324	B26		220-T4			10.0		0.3		Soln. H.T. (b)	46	42	25	14	12	75	33	7	4.5	A	220-T4	Good corr. resistance; highest toughness.
39	B26	CN21	142-T571	4.0		1.5		1.0	2 Ni	Soln. H.T.; Aged (C)	32	29	28	0.5		85	27	8		C	142-T571	Good strength, stability at elevated temperatures.
										PERMANENT MOLD CASTINGS											
33	B108	C3	113	7.0	2.0		1.7	1.4		As Cast	28	24	19	2		70	23			D	113	Low cost alloy. Not heat treated.
			C113	7.0	3.5					As Cast	30	25	24	1		80	22	9.5		D	C113	-"- -"- -"- -"- -"- -"-
			138	10.0	4.0	0.3				As Cast	28	26	24	0.5		100	22			D	138	High temperature strength, hardness.
	B108	SC1	A108	4.5	5.5			1.0		As Cast	28	24	16	2		70	25			D	A108	Good casting properties.
35	B108	S1,S2	43		5.0			0.8		As Cast	24	21	9	9	5	45	18			B	43	Al-Si alloys have excellent casting properties and
37					12.0			0.8		As Cast										B		corrosion resistance.
			A214			3.8	1.8			As Cast	27	22	16	7	2.5	60	22			A	A214	Excellent resistance to corrosion.
380	B108	CS4	B195-T6	4.5	2.5			1.2		As Cast	45	35	33	5	2	90	32	10		C	B195-T6	High strength, heat treatable alloy.
34	B108	CG1	122-T52	10.0		0.2		1.5		Soln. H.T. (b)	35	30	31	1		100	25			D	122-T52	Standard piston alloy. High temp. strength and
34	B108	CG1	122-T65							Soln. H.T.; Aged (C)	48	40	36			140	30	9		D	122-T65	good wear resistance.
39	B108	CN21	142-T61	4.0		1.5		1.0	2 Ni	Soln. H.T.; Aged (C)	47	40	42	0.5		110	31	9.5		C	142-T61	High temp. strength and stability.
321	B108	SN41	A132-T65	0.8	12.0	1.2		1.3	2.5 Ni	Soln. H.T.; Aged (C)	47	40		0.5		125	27			C	A132-T65	Pistons. Reduced thermal expansion.
	B108	SC41		1.5	12.2	0.5		0.9	0.75 Mn	Soln. H.T. (b)		33			3					C		Piston alloy.
300			152-T74	7.0	5.5	0.3		1.5		Soln. H.T.; Aged (C)	35	30	26	0.5		100	29			D	152-T74	-"- -"-
322			355-T6	1.3	5.0	0.5		0.6		Soln. H.T.; Aged (C)	43	37	27	4	1.5	90	30	9		C	355-T6	Good strength at elevated temperatures.
323	B108	SG1	356-T6		7.0	0.3		0.6		Soln. H.T.; Aged (C)	40	33	27	5	3	90				A	356-T6	Intricate castings. High temp. strength.
			750-T533	1.0				(1 Ni)	6.5 Sn	Soln. H.T.; Aged (C)	20	18	8.5	10	8	45	14	9			750-T533	Bearing alloy.
										DIE CASTINGS									Charpy (f)		
304	B85	S4	43		5.0			2.0		As Cast	30	29	14	7	3.5				4.5	B	43	Tough, corrosion resistant, good casting properties.
305	B85	S5	13		12.0			2.0		As Cast	37	33	18	18	1.5			15	2	B	13	Corrosion resistant; good casting properties.
			360		9.5	0.5				As Cast	42		23	18						B	360	High strength and corrosion resistance.
E306	B85a	SC6	380	3.5	8.5			1.3		As Cast	45	34	25	2	2				2.5	D	380	High strength and hardness.
307	B85	SC2	85	4.0	5.0			2.3		As Cast	40	23	22	3.5	2			17	2.5	D	85	-"- -"- -"- -"-
312				7.0	2.0		1.7	2.3		As Cast		33			1				3.2	D		Low cost, general purpose alloy.
			218			8.0				As Cast	42		23	7				18		A	218	High corrosion resistance, strength, toughness.

(a) Aluminum Co. of America alloy numbers. Heat treated alloys designated by letter T and heat treatment number after alloy number. T4 is solution treatment.

(b) Solution heat treatment: soaking at high temperature followed by quenching.

(c) Solution heat treatment followed by artificial aging above room temperature.

(d) In thousands of pounds per square inch. Yield strength taken at 0.2% permanent set.

(e) 500 million cycles in reverse bending.

(f) Modified Charpy impact toughness; 40-mm span.

(g) Relative resistance to salt water corrosion. A = best.

Metal Progress Data Sheet, November 1940, Page 81a

Solid Quality *Solid Durability*

Solid Protection

Solid Beauty

. . . in modern moldings fabricated of

Stainless moldings, economically produced in volume with Superior Stainless Strip Steel, provide protection with beauty, brilliance and *permanence.*

Choose SUPERIOR for your moldings fabrication, and get the benefits of *easier handling* through precision composition, exact temper, uniform dimensions and long coil lengths in the right grades for the job!

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STAINLESS STRIP STEEL

SUPERIOR STEEL CORPORATION

CARNEGIE · PENNSYLVANIA

Corrodibility of Some Common Metals and Alloys

Estimates are relative only; service temperatures are usually the deciding factors in designing equipment

Originally compiled (1933) by Jerome Strauss; revised (1946) by E. E. Thum using data furnished by several specialists

Class of Material	Nominal Composition: Carbon	Chromium	Nickel	Silicon	Copper	Other Constituents	Atmospheres: Sea Shore	Atmospheres: Industrial	Water: Domestic	Water: Mine	Water: Sea	Water: Saline with H_2S	Water: Brackish with NaCl	Water: Wet Steam	Oxidation Resistance Max. Safe Temp. °F.: Oxidizing Gases	Oxidation Resistance: Reducing Fuel Gas	Oxidation Resistance: Sulphur Rich Gas	Fruit, Vegetable Juices	Dairy Products	Other Food Products	Acids Moderate Concentration 5-15%: HCl	H_2SO_4	HNO_3	Acetic	Phosphoric	Alkalies: 1 to 20% Sol	Alkalies: Fused	Salt Solutions Medium Concentration: NH_4Cl	$MgCl_2$	$MgSO_4$	Hot Sulphite Liquor	Dye Liquor	Refinery Crudes Below 400°F: Sweet	Refinery Crudes Below 400°F: Sour
Ingot iron or wrought iron	0.03				0.08		P	P	F	P	F	F	F	FG				P	P	P	P	P	P	P	P	G	G	F	P		F	P
Low C steel	0.10				0.08		P	P	F	P	F	F	F	FG	1000	1000		P	P	P	P	P	P	P	P	G	G	F	P		F	P
Copper and high tensile steels	0.10				0.25		F	F	F	P	F	F	F	FG				P	P	P	P	P	P	P	P	F	G	P	P		F	F
Hot galvanized iron & steel							G	G	FG	PF	FG	FG	FG	FG				P	P	P	P	P	P	P	P	F	G	FB	FG		G	P
Calorized iron & steel							G	G	P	P	P	P	P	P	1650	1650	1650	P	P	P	P	P	P	P	P	F	G	P	P		G	FG
Grey cast iron	2.8 graphite, 0.7 combined carbon						F	FG	G	F	F	F	F	F				P	P	P	P	P	P	P	P	G	F	P	P	P	G	F
High silicon iron	0.60			14.25			E	E	E	G	E	E	E	E				P	P	E	FG	P	P	G	P	FG	G	P	P		G	F
Nickel cast iron	3.30		3.50	1.50			FG	FG	F	F	FG	FG	FG	F	1200	1200		P	P	P	P	P	P	G	P	GE	FG	G	FG		FG	PF
Chromium cast iron	2.50	25.00		2.00			G	G	G	G	FG	FG	FG	G	1750	1750	1750	G	F	P	G	P	P	F	G	E	FG	P	FG		G	G
Ni-Cr-Cu cast iron	3.00	2.00	14.00	1.50	6.00		G	G	G	F	F	G	G	G	1400	1400	1200	PF	P	P	G	P	P	FG	P	FG	E	G	P	PF	F	G	G
Nickel steel: Low Ni	0.18		3.00				FG	FG	F	F	F	FG	F	F				P	P	P	P	P	P	FG	P	FG	E	G	FG		FG	PF
High Ni	0.30		28.00				G	G	G	FG	G	G	G	G				P	F	F	G	P	P	FG	F	GE	G	FG	G		G	G
Chromium steels: 5% Cr	0.15	5.00				Mo 0.5	F	F	F	P	F	P	F	FG	1150	1150	1150	P	P	P	P	P	P	P	P	G	FG	P	P	P		G	F
7% Cr	0.15 max.	7.00		0.75		Mo 0.5	F	F	F	P	P	P	P		1250	1250	1200	P	P	P	P	P	P	P	P	G		P	P	P			G
9% Cr	0.15 max.	9.00		0.50		Mo 1.0	F	F	F	P	P	P	P		1300	1300	1250	P	P	P	P	P	P	P	P	G		P	P	P			G
12% Cr	0.10 max.	12.00					G	G	G	F	PF	PF	PF	G	1350	1350	1300	G	FG	G	P	P	G	G	Fa	G	P	F	G	G	F	E	G
17% Cr	0.10 max.	17.00					G	G	G	FG	PG	PG	PG	G	1550	1550	1500	GE	G	GE	P	P	E	G	Ea	G	P	FG	G	G	F	GE	GE
17% Cr, 4% Mo	0.10 max.	17.00				Mo 4.0	G	G	G	FG	PG	PG	PG	G				G	G	G	P	P	E	G	G	G	P	FG	G	G		E	GE
27% Cr	0.35 max.	27.00		0.75		N 0.25	GE	G	G	GE	G	FG	FG	E	1900	1900	1800	E	F	G	P	P	E	F	G	G	P	P	G	E	GE	E	E
Silicrome; (8% Cr, 3% Si)	0.45	8.25		3.50			F	FG	F	F	PF	PF	PF	FG	1500			F	F	F	P	P	FG	FG	P	G	P	P	FG	P	PG	E	GE
Cr-Ni steels: 8-20	0.20	8.00	20.00				G	G	G	FG	PG	F	FG	GE	1500	1500		G	FG	G	P	FG	F	G	FG	E	G	FG	G	G	F	GE	GE
18-12, 2½% Mo	0.15	18.00	12.00			Mo 2.5	E	E	E	E	FE	FE	FE	E				E	E	E	PF	G	E	E	E	E	F	GE	G	G	G	E	E	E
18-8	0.10	18.00	8.00				E	G	E	FE	FG	PG	FG	E	1650	1650	1100	GE	E	E	P	PG	E	E	E	E	F	G	G	G*	G	GE	F	E	E
18-12	0.10	18.00	12.00				E	G	E	FE	PG	PG	PG	E	1650	1650	1100	E	E	E	P	F	G	G	G	E	F	G	G	G	G	G	PG	E	E
18-35	0.50 max.	18.00	35.00	1.00			E	G	E	FG	PG	PG	PG	E	2100	2000	1900	E	E	E	F	P	G	E	G	E	F	G	G	G*	G	G	PG	E	E
25-12	0.25 max.	25.00	12.00				E	G	E	G	G	PG	G	E	2100	2000		E	E	E	P	P	F	G	E	E	F	G	G	G*	G	GE	E	E	E
25-20	0.25 max.	25.00	20.00	1.50			E	G	E	G	G	E	G	E	2100	2000		E	E	E	P	P	F	G	G	E	FG	G	G	G	G	G	E	E	E
Stellite	3.0 max.	30.00				Co 55.0, W 15.0	E	E	E	E	E	E	G	E	2100	2100		E	E	G	F	G	F	FG	E	E	E	E	E	E	E	E	E	E	E
Hastelloy A			55.00			Mo 20.0, Fe 20.0	G	G	G	F	G	F	G	E	1400	1800	P	G	G	G	E	G	P	P	E	E	E	E	E	P	P	E	G	E	E
Hastelloy B			64.00			Mo 28.0, Fe 6.0	G	G	G	G	G	F	G	E	1400	1800	P	G	G	G	E	G	E	P	E	E	E	E	E	P	P	E	E	E	E
Hastelloy C		14.00	58.00			Mo 17.0, W 5.0, Fe 6.0	E	E	E	E	E	E	E	E	2100	2100	P	E	E	G	F	G	P	P	E	E	E	E	E	P	P	E	E	E	E
Hastelloy D			85.00	10.0	4.0		G	G	G	P	G	F	F	G				G	G	G	G	E	E	P	E	E	E	E	E	P	P	E	E	E	E
Commercially pure Ni			99.20				E	G	E	FG	FE	FE	FE	E	1900	2300	1000	G		GE	FG	FG	P	FG	FG	E	E	G	E	E	P	P	E	E	GE
Nickel alloys: Monel metal	0.15		67.50	0.50	28.50	Mn 1.50	E	G	E	PE	GE	GE	GE	E	1000	2000	1000	G	FG	FG	G	P	F	FG	G	E	E	GE	GE	E	E	E	G	E
Nichrome, 60-15	0.12	15.00	60.00				E	G	E	G	FE	FE	FE	E	2050	1900	P	E	E	E	F	F	F	G	G	E	E	G	E	E	E	E	E	E
Inconel, 14% Cr		14.00	80.00			Fe 6.0	E	G	E	G	FE	FE	FE	E	2000	2100	1500	E	E	E	F	F	F	G	G	E	E	G	E	E	E	E	E	E	E
80% Ni, 20% Cr		20.00	80.00				E	G	E	G	FE	FE	FE	E	2000	2100	1500	E	E	E	FG	FG	G	G	G	E	E	G	F	E	E	E	E	E	E
Commercially pure Cu					99.90		G	G	G	FG	G	PF	FG	G				FG	P	FG	PG	FG	P	FG	FG	E	P	E	G	G	FG	FG	PF	PF
Copper alloys: Red brass					85.00	Zn 15.0	G	G	FG	FG	G	PF	FG	G				P	P	FG	PF	FG	P	FG	FG	G	F	FG	G	G	G	G	G	F	F
Tobin bronze					60.00	Zn 39.2, Sn 0.75	G	FG	FG	F	G	F	FG	G				FG	P	FG	P	P	F	F	F	FG	PF	FG	G	G	FG	FG	B	G	F	F
Phosphor bronze					95.00	Sn 5.0	G	FG	G	F	G	FG	G	G				PF	P	P	P	P	F	FG	FG	G	F	FG	G	G	G	F	FG	G	F	F
Silicon bronze				3.00	95.00	Mn 1.0 or Zn 1.5, Sn 0.5	G	G	G	FG	PG	PF	PG	G				F	P	P	F	F	FG	P	P	G	F	FG	G	G	G	G	FG	G	F	F
Aluminum bronze			0.50		90.00	Al 9.0, Fe 0.5	G	G	G	FG	G	G	G	G				F	F	P	F	F	FG	P	P	FG	PF	FG	G	G	G	G	FG	FG	G	F
Nickel silver			20.00		75.00	Zn 5.0	G	G	G	G	GE	FG	FG	G				FG	PF	G	F	P	FG	P	P	FG	FG	FG	G	G	G	G	FG	FG	G	FG
Admiralty metal					70.00	Zn 29.0, Sn 1.0	G	B	G	FG	FG	FG	FG	G				FG	P	FG	P	P	FG	P	P	FG	F	FG	G	G	G	F	FG	G	G	F
Commercially pure Al						Al 99.20	GE	E	FG	PG	G	G	PG	G	800	800	800	F	G	G	P	P	F	P	P	G	P	P	P	P	F	FG	E	E	E
Aluminum alloys: 3S						Al 98.8, Mn 1.2	GE	E	FG	PG	G	G	PG	G	800	800	800	G	GE	GE	P	P	F†	P*	G*	P	P	P	P	F	FG	E	E	E
Alclad 3S	Duplex product; 10% Al alloy over 3S						E	E	GE	PG	GE	GE	PG	G	800	800	800	FG	FG	G	P	P	F†	P*	G*	P	P	P	P	F	GE	P	E	E	E
24S-T					4.50	Mn 0.6, Mg 1.5, Al bal	PG	FG	PF	P	P	P	P	PF	P	P	P	F	F	F	P	P	F	P	P	P	P	F	GE	P	F	F	E	E	E
Alclad 24S-T	Duplex product; 5% Al coating over 24S-T						E	E	GE	PG	GE	GE	PG	G	300	300	300	FG	FG	G	P	P	P†	P*	F†	P	P	P	P	F	GE	P	F	F	E	E
61S-T		0.25		0.60	0.25	Mg 1.0, Al bal.	GE	E	FG	PG	G	G	PG	G	800	800	800	G	GE	GE	P	P	F†	P*	G†	P	P	P	P	F	GE	P	F	F	E	E
Commercially pure Mg							G	G	F	P	P	P	P	P		400	400	P	P	PE	P	P	P	P	F	E		P	P	P		PE		
Cast Mg alloys	A.S.T.M. AZ63, AZ92, AZ90						F	G	F	P	P	F	P	P		400	400	P	P	PE	P	P	P	P	F	E		P	P	P		PE		
Wrought Mg alloys	A.S.T.M. M1, AZ31X, AZ61X, AZ80X						G	G	F	P	F	F	F	P		400	400	P	P	PE	P	P	P	P	F	E		P	P	P		PE		
Commercially pure Sn							G	G	E		G			G				P	G	G	P	P	P	P	P	F	P				D			
Commercially pure Pb					0.06	Pb 99.90	G	G	PG	G	G			G				P	P	P	F	E	P	P	G	P	P	FB	FG	G	F			

E = Excellent; almost unlimited service
G = Good; will give good service
F = Fair
P = Poor

a Below 50°C.
* May crack under certain conditions

† GE for fuming H_2SO_4
† E for HNO_3 above 80%
† E for glacial acetic

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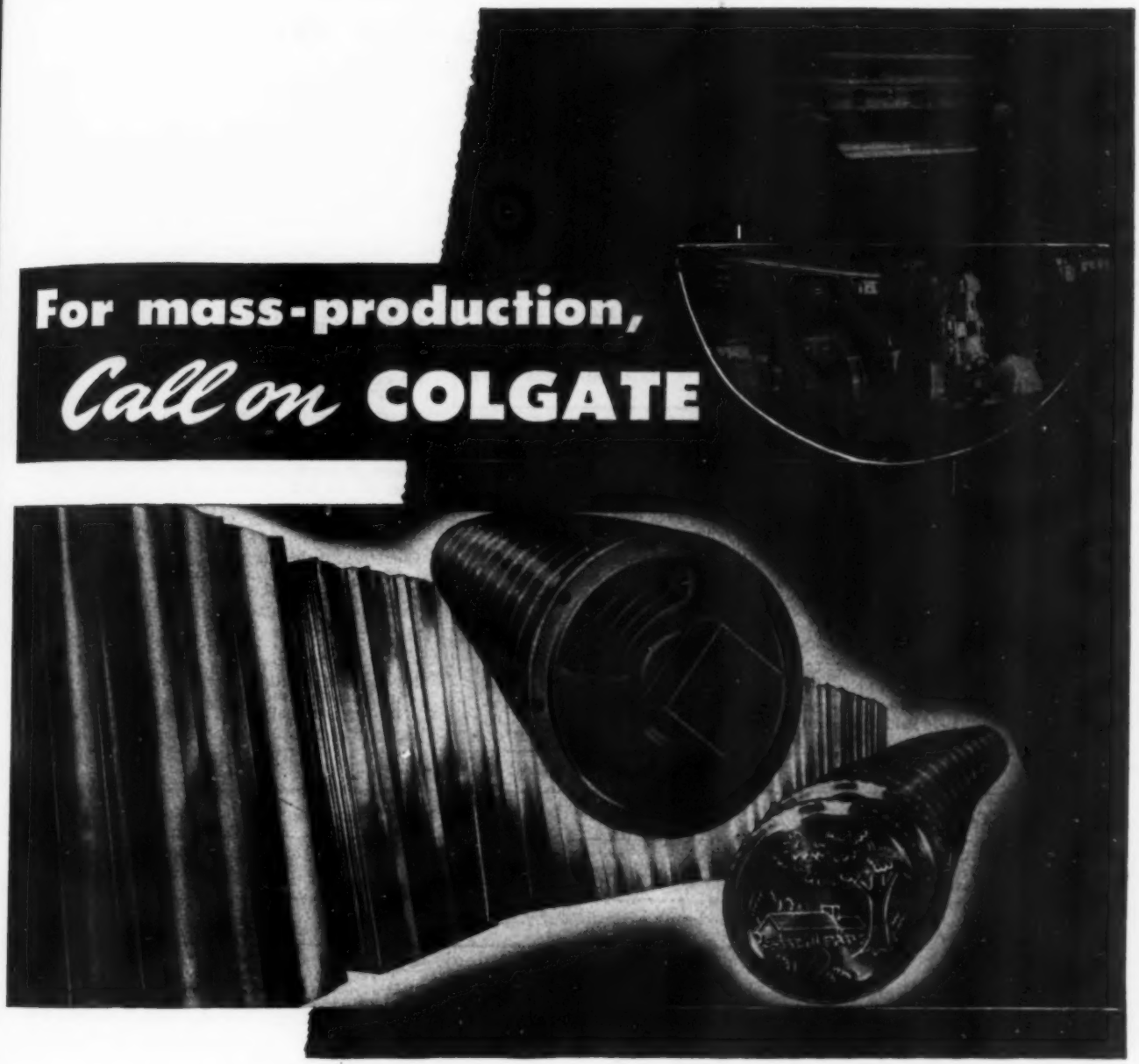

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Engineering Properties of Monel

Data from
International Nickel Co., Inc.

MONEL is a solid solution of nickel and copper approximately 67:30, with added elements to control certain properties. Typical compositions are as shown at right:

PRODUCT	NI	CU	FE	MN	SI	C	AL	S
Wrought: Regular	67	30	1.4	1.0	0.1	0.15	....	(Note)
"K" (heat treatable)	66	29	0.9	0.85	0.50	0.15	2.75	0.005
Cast; Regular	63	32	1.5	0.75	1.6	0.15	....	.....
"H" (high strength)	63	31	2.0	0.75	3.0	0.1	....	.....
"S" (non-galling)	63	30	2.0	0.75	4.0	0.1	....	.....

(Note) A high sulphur variety called "R" Monel is free machining.

Properties of Monel Castings

PROPERTY	REGULAR	H MONEL	S MONEL
Tensile strength (1000 psi.)	65 to 90	90 to 115	110 to 145
Yield (1000 psi. for 0.5% extension)	32 to 40	60 to 80	80 to 115
Elongation (% in 2 in.)	45 to 25	20 to 10	4 to 1
Izod impact, ft-lb.	80 to 65	45 to 35	9 to 3
Brinell hardness	125 to 150	175 to 250	275 to 375
Rockwell number	55 to 75-B	.....	<32-C

Temperature for slight oxidation ..... 570° F.
Annealing range (standard monel) ....1400 to 1800° F.
Forging range (standard monel) .....2150 to 1200° F.
Pouring range for castings .....2650 to 2850° F.

Cold-Rolled Sheet and Strip

TEMPER	SHEET		STRIP		APPROX. TENSILE STRENGTH
	SHORE	ROCKWELL B	SHORE	ROCKWELL B	
Dead soft	16 max.	60 max.	16 max.	60 max.	70,000
Soft	.....	.....	17 to 18	61 to 68	75,000
Soft skin-hard	17 to 20	61 to 73	.....	.....	.....
Skin hard	.....	.....	19 to 20	69 to 73	77,500
Quarter hard	21 to 24	74 to 82	21 to 24	74 to 82	80,000
Half hard	25 to 30	83 to 89	25 to 30	83 to 89	90,000
Three quarter	31 to 35	90 to 93	31 to 35	90 to 93	100,000
Hard	36 min.	94 min.	36 to 40	94 to 97	110,000
Full hard (strip)	.....	.....	41 min.	98 min.	120,000

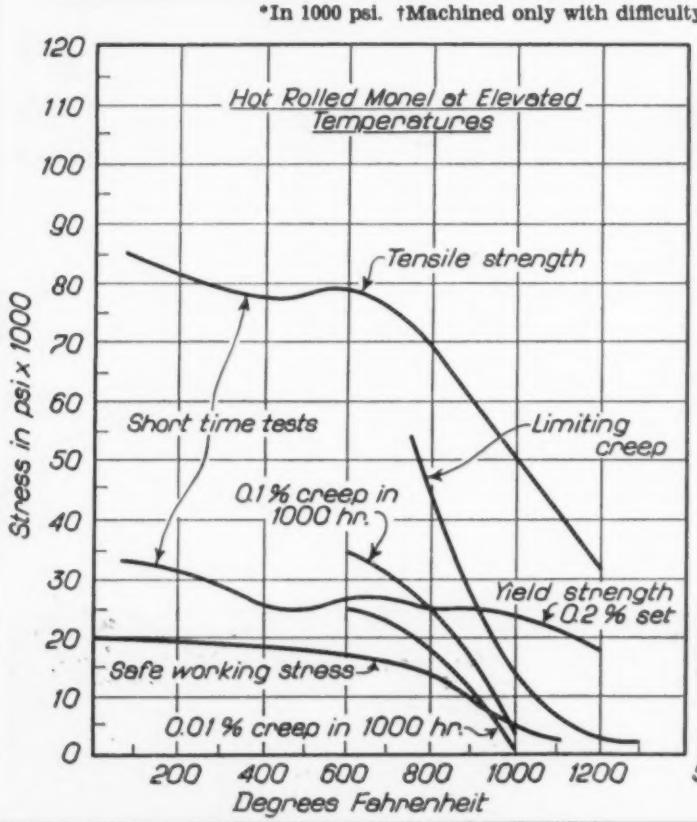
Physical Constants of Wrought Monel

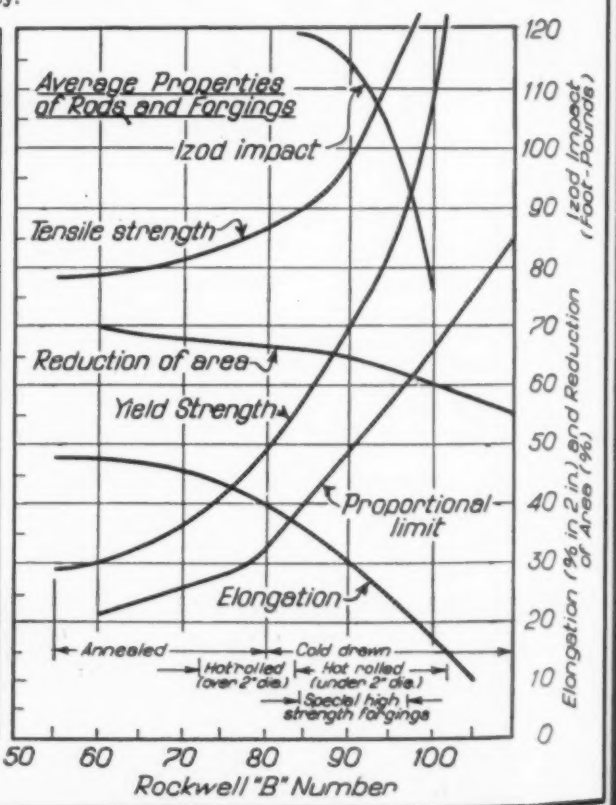
Specific gravity 8.84
Density, lb. per cu.in. 0.319
Melting range
degrees F. .....2370 to 2460
degrees C. .....1300 to 1350
Specific heat at (80° to 212° F.)
(27° to 100° C.) 0.127
Heat expansion coefficient
at 80° to 212° F., per °F.....0.0000078
at 25° to 100° C., per °C.....0.000014
Thermal conductivity
at 80° to 212° F., B.t.u./sq.ft./hr./° F./in. 180
at zero to 100° C., cal./sq.cm./sec./° C./cm. 0.062
Electrical resistivity
at 32° F., ohms/circ.mil.ft. 290
at 0° C., microhms/cm.³ 48.2
Temperature coefficient of electrical resistivity
per ° F. 0.0011
per ° C. 0.0019
Modulus of elasticity
in tension, psi. 26,000,000
in torsion, psi. 9,500,000
Poisson's ratio 0.32

Mechanical Properties of K Monel

CONDITION (K MONEL)	ULTIMATE*	YIELD (0.5% SET)*	ELONGATION	REDUCTION	BRINELL
Soft, quenched from 1450° F.	<120	<60	>35	>50	>180
Reheated to 1100° F.	120 to 140	80 to 100	>30	>35	225 to 275
Cold worked and reheated to 1100° F.	>160	>120	>15	>20	>325†

*In 1000 psi. †Machined only with difficulty.





Requirements of Steels for High Temperature Service

By Claude L. Clark

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SO MUCH attention has been given during the past wartime years to the "superalloys" for gas turbines to operate at 1300 to 1500° F. and even higher, that substantial developments in steels containing only a few per cent of alloys have passed with little notice. Yet these steels have been giving satisfactory service in chemical plant, petroleum refineries and in high pressure steam service under what used to be called (and what will be called in this article) "high temperature" conditions. It will be my endeavor to describe, in some detail, the present situation regarding a series of chromium steels containing from 5.0 to 9.0% chromium, inclusive. They may be called "intermediate" alloy steels because of their position between the engineering alloy steels (usually containing less than 4% combined alloy) and the true "stainless" steels, containing at least 12% chromium.

Historically the facts are set forth in E. S. Dixon's chapter in "The Book of Stainless Steels". A great deal of seamless tubing containing about 5% chromium was installed in pressure still equipment in 1927 and 1928, and it was found to have excellent resistance against oils and crudes containing hydrogen sulphide or other sulphides that attacked ordinary steel. It had good strength and toughness at operating temperatures, and had the important property of swelling gradually when overloaded, rather than bursting or splitting. However, it was so brittle when cooled after a long run that many tubes broke when a turbocleaner was run through them to cut out the accumulated coke; this work therefore had to be done before the still had cooled down. About 0.50% molybdenum was found to mitigate this fault, but it was first added (about 1932) to increase the strength at elevated temperature. About the same time some tubes were made with a content of titanium which rendered the alloy nonhardenable, hence more weldable and less likely to be damaged by heating in the field during installation or repairs.

Qualifications

Before detailing the changes in these intermediate chromium steels in the last decade, it will be well to review briefly the properties looked for in steels for high temperature service.

Suitable room temperature properties in the as-received condition are necessary, for the strength, ductility, hardness and impact characteristics must be such as to permit installation in the desired equipment. These properties can be readily determined and, in fact, they usually serve as the basis for inspection.

Next comes their load-carrying ability at high temperature — not so easily estimated. The interpretation placed on load-carrying ability also varies depending upon the particular type of application under consideration. For example, in steam turbine parts, bolting and valves, the operating temperature is generally fairly constant, permissible tolerances are small and consequently the creep strength for extremely slow rates of deformation is the basis of design. In certain other equipment, such as oil cracking still tubes, the temperature may increase continuously during the operating cycle, and bulging, when it does occur, takes place over a relatively short time at the more elevated temperatures; consequently for this type of service load-carrying ability implies

Table I — Classification of High Temperature Applications

I. On Basis of Physical Requirements:

- A. Permissible deformation during service
  - Decidedly limited
    - Steam turbines
    - Valve parts
    - Bolting
  - Up to 5.0%
    - Cracking still tubes
    - Superheater tubes
    - Heat exchangers
- B. Constant versus varying temperature
  - Constant
    - Steam turbines
    - Steam lines
    - Bolting
  - Varying
    - Cracking still tubes
    - Superheater tubes
- C. Relative importance of strength and stability
  - Petroleum industry
    - Sweet crude
      - Strength
      - Oxidation resistance
    - Sour crude
      - Corrosion resistance
      - Strength
  - Central stations
    - Strength
    - Oxidation resistance
    - Corrosion resistance (steam)

II. On Basis of Industry:

- A. Central stations
  - Superheater tubes — 1000 to 1300° F.
  - Steam lines — 850 to 1050° F.
  - Steam turbine — 850 to 975° F.
- B. Petroleum
  - Liquid — Temperature varies with cycle
  - Vapor — Temperature varies with cycle
- C. Miscellaneous
  - Chemical equipment
  - Furnace parts
  - Heat treating equipment

more rapid rates of deformation. Unfortunately with many of the high temperature steels — and especially those of the type under consideration — the high temperature load-carrying ability may vary considerably with the *rate* of deformation used in the laboratory equipment for its determination. In other words, the steel which is outstanding in its creep strength may at the same time be inferior under more rapid rates of deformation such as are used in the stress-rupture test or the short-time tensile test.

In the third place, surface stability is just as important as load-carrying ability, for while the strength characteristics indicate the stress the steel is capable of withstanding the surface stability determines the length of time it will be able to carry this stress. Insofar as high temperature applications are concerned, lack of surface stability is indicated by oxidation or corrosion of either the general or the intergranular type. Of these two, intergranular attack is the more serious.

In addition to strength and surface stability, high temperature steels must also possess a high degree of *microstructural stability*, and be capable of retaining good ductility and shock resistance both at the operating temperature and at room temperature after it has been cooled from its service at elevated temperatures.

Table I classifies high temperature applications, both on the basis of physical requirements and on the basis of industrial installations, and is included to show that the emphasis placed on the requirements just listed varies considerably in different industries and also in different applications within the same industry. Since the requirements for satisfactory service vary so greatly it follows that the methods for evaluation must also be adjusted so as to give the desired information. The more common means used for this purpose on heat treated bars, plates or tube stock are summarized below.

Room temperature tests
Tensile, Brinell, impact, metallographic

Load-carrying tests
Short-time high temperature tensile, creep, stress-rupture

Surface stability tests
Oxidation, corrosion, metallographic examination of surface of stress-rupture test pieces

Microstructural stability tests
Test pieces from load-carrying tests
Room temperature tests on same and on parts from service
Heat embrittlement tests

Hot ductility tests
On creep and stress-rupture tests and on parts from service

Hot toughness tests
Impact tests at high temperature, short and long stay.

Alloying Elements

Theoretically, at least, every element in the periodic table is available for development of new steels. Many concerned with the selection of steels for high temperature service probably feel that certain of the more recent alloys contain most of these! Actually, however, few have as yet been employed and these can be classified rather simply.

Table II shows two convenient methods of classifying these common alloying elements. The first is based on whether the elements go into solution with the dominant iron or prefer to combine with whatever carbon is present. Certain of the elements fall in both classes, because after all of the available carbon is consumed the remainder will go into solution. While this is probably true of all of the carbide formers, the majority of these are added in such limited quantities that little is present in solution.

Table II — Classification of the More Common Alloying Elements

I. Solid Solution Versus Carbide-Forming Elements	
A. Solid solution	B. Carbide formers
Nickel	Chromium
Chromium	Manganese
Silicon	Molybdenum
Manganese	Tungsten
Aluminum	Columbium
Copper	Titanium
Cobalt	Vanadium
II. Ferrite Versus Austenite Formers	
A. Ferrite	B. Austenite
Chromium	Carbon
Silicon	Nitrogen
Aluminum	Nickel
Molybdenum	Manganese
Tungsten	Cobalt
Vanadium	Copper
Columbium	
Titanium	

The second classification is based on whether the alloy element promotes the formation of ferrite or of austenite. This differentiation is not as widely made as the one just mentioned, and justifies further discussion. First, however, it should be recognized that the elements align themselves differently under the two methods of classification; that is, all of the solid solution elements are not austenite formers, and all of the carbide formers are not ferrite formers.

Generally speaking, if enough of the "ferrite formers" are added to iron (or low carbon steel) it becomes incapable of being hardened by quenching because the austenitic phase does not exist at high temperature. This is shown on the binary alloy diagram — iron-chromium or iron-silicon, for example — as a "gamma loop", such as shown in Fig. 1. More and more chromium depresses the A_4 temperature, where γ changes to Δ iron and vice versa, until A_4 finally meets A_3 and "closes the loop" as at point M, Fig. 1. This occurs at about 12.8% chromium in pure iron; the phase region $\alpha+\gamma$ theoretically demanded is rather narrow and with greater chromium additions the steel remains ferritic regardless of the temperature to which it is heated.

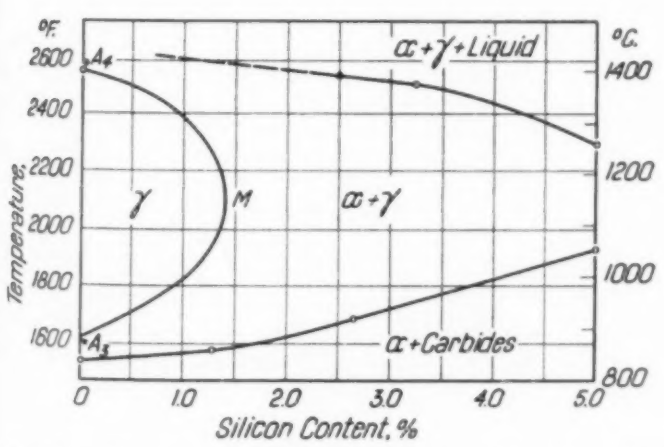


Fig. 1 — Phase Boundaries of Complex 5% Chromium Steel Base as Silicon Varies. Analysis of base: 0.12% carbon, 5.0% chromium, 0.55% molybdenum, 0.55% aluminum

In the plain 5% chromium steel containing, say, 0.15% carbon (A.I.S.I. type No. 501), there is not enough chromium to suppress the gamma phase. Consequently when it is soaked at about 1600° F. the microstructure becomes a more-or-less uniform austenite, and this changes to a finely granulated martensitic structure on air cooling (Fig. 2) or precipitates some excess ferrite on furnace cooling (Fig. 3).

Those other elements designated in Table II as ferrite formers behave in the same manner; on the other hand, the austenite formers extend, rather than contract, the area over which this loop exists. The effectiveness of the ferrite formers in their ability to close the gamma loop varies; aluminum and vanadium are the most powerful in this respect; only about 1.0% of either is necessary to render the alloy ferritic; and thus these alloys may be said to be 12.5 times as effective as chromium. With silicon, about 2.2% is required — it is 5.8 times as effective as chromium — and with

molybdenum, about 3.0% — 4¼ times as effective. (These relationships are true only in the substantial absence of carbon in the alloy in question, for this element, being an austenite former, will *extend* the gamma loop.)

When more than one ferrite former is present in the same steel they exert additive effects but their effectiveness in this respect may not be the same as that indicated by the corresponding binary system. The loop is further modified by the presence of carbon, for it may cause the mixed $\alpha+\gamma$ region to occupy an area several times as wide as that of the homogeneous austenitic γ field at its maximum extension.

This condition is illustrated in Fig. 1, which maps the constitution of a steel with 0.12% C, 5.0% Cr, 0.55% Mo, and 0.55% Al, but with varying silicon. The inner gamma loop is closed at 2100° F. with a silicon content of 1.40%, but the outer loop — that is, the mixed $\alpha+\gamma$ region — is not closed even with 5.0% silicon. This region is therefore over four times as wide as the homogeneous gamma area. The equivalent chromium content, at the closing of the inner gamma loop and at its temperature of maximum solubility, is 22.2 (assuming that each of the elements exerts the same influence as in the corresponding binary system*). This figure is considerably in excess of that reported for the required amount of chromium to close the loop in the iron-chromium-carbon system containing 0.12% carbon (about 18% chromium, according to Bain) and thus indicates that certain of these elements are more effective in the presence of carbon than when this element is absent.

While it is true that the austenitic phase at high temperatures is by no means completely suppressed in these intermediate alloy steels, and that the ferrite formers may not have the same effectiveness when present simultaneously, or in the presence of carbon, as indicated by their behavior in the binary system, a fair indication as to the number of phases to be expected in new steels can be obtained by using the approximate equivalence factors. At least this procedure will classify all except those with a borderline analysis. In determining the equivalent chromium content on this basis allowance must of course be made for the austenitic formers that may also be present, and for this purpose manganese and nickel have been assigned twice the effect of

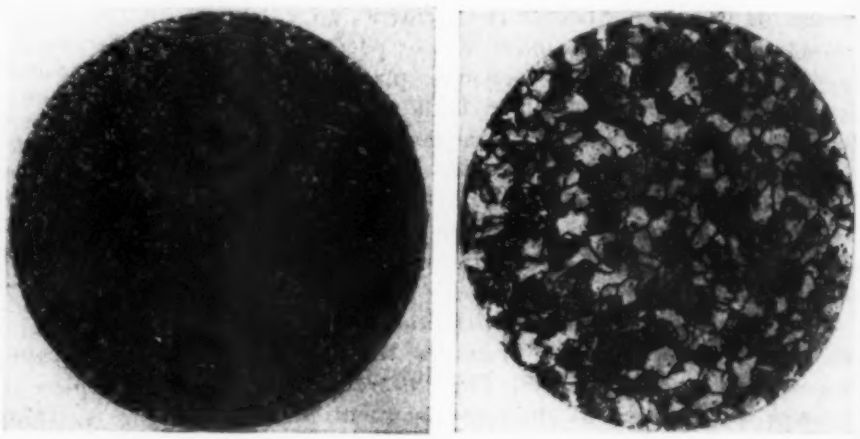


Fig. 2 and 3 — 5% Plain Chromium Steel (0.15% Carbon), Air Cooled and Furnace Cooled From 1600° F. Hardness 401 and 145 Brinell, respectively. Etched with 4% HNO_3, magnified 100 diameters (Wright)

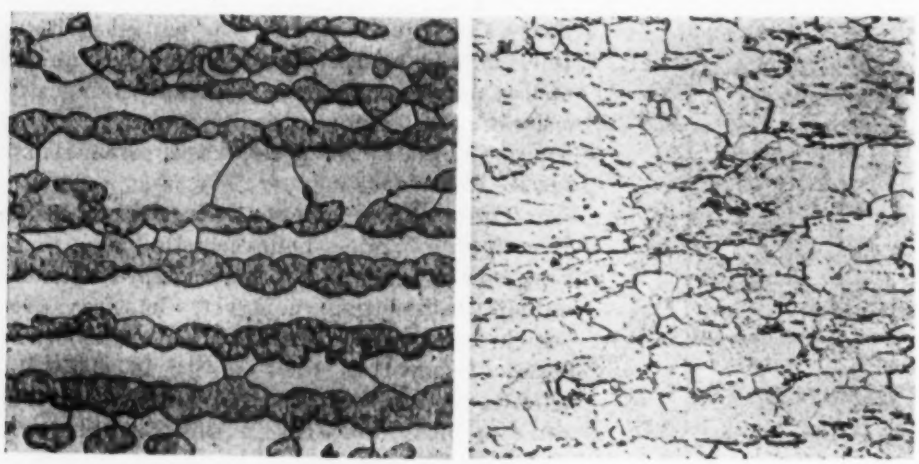


Fig. 4 — High Alloy, Low Carbon Steel, Quenched From $\alpha+\gamma$ Region of Stability, Thus Retaining the Two-Phase Structure. Fig. 5 — Structure of Similar Steel, Annealed, Consisting of Alpha Grains With Small Particles of Carbide. Etchant: aqua regia. Magnification: 400 diameters (Krivobok)

*Cr + 4¼ Mo + 12.5 Al + 5.8 Si
= 5.0 + 4¼ · 0.55
+ 12.5 · 0.55 + 5.8 · 1.4
= 22.2

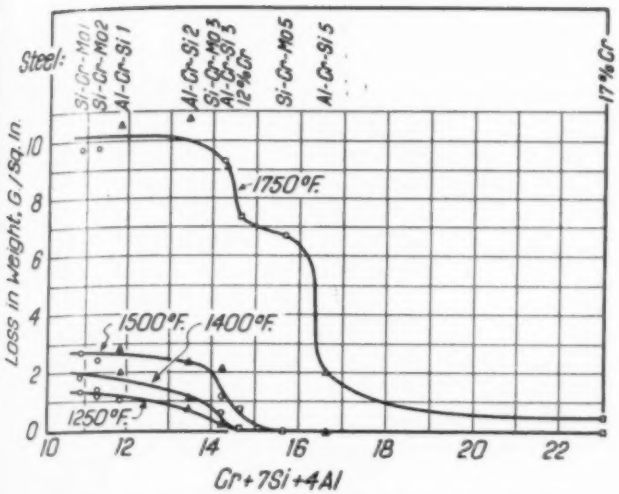


Fig. 6 — Relationship Between Oxidation Resistance at Various Temperatures and Chemical Composition of Steel Figured as Cr + 7Si + 4Al

the dominant element chromium, and carbon 40 times the effect.

All this is of interest but the question may properly be raised as to its practical importance. It is highly advisable to know the structural characteristics of the steel under consideration; otherwise considerable trouble may be encountered. From the producer's standpoint: If the steel contains two phases at the fabrication temperature, then each phase will have different hot working characteristics and, if this is not realized, tearing and splitting is apt to occur. Likewise during any cold working operation, such as drawing, the same condition may exist. Further, if the steel is either $\alpha+\gamma$ (as in Fig. 4) or entirely α or ferritic, as in Fig. 5, the refining of the grain size, after fabrication, will have to be accomplished by the correct amount of cold work, followed by a heating for recrystallization, rather than (as in plain carbon steel) by a simple heating above the upper transformation temperature.

From the user's standpoint, two-phased and ferritic steels are apt to have a low resistance to shock or impact. If, as in the removal of coke from oil cracking still tubes, the steel is to be subjected to shock, this should be done at slightly elevated temperatures, such as at 400° F., rather than when at outside temperature. If the steel is to be heated to high temperatures during installation, such as in the bending of large pipe, it must also be recognized that the grain size cannot later be completely refined by a simple heat treatment.

It is not intended to imply that either two-phased or ferritic steels may not be capable of rendering satisfactory high temperature service,

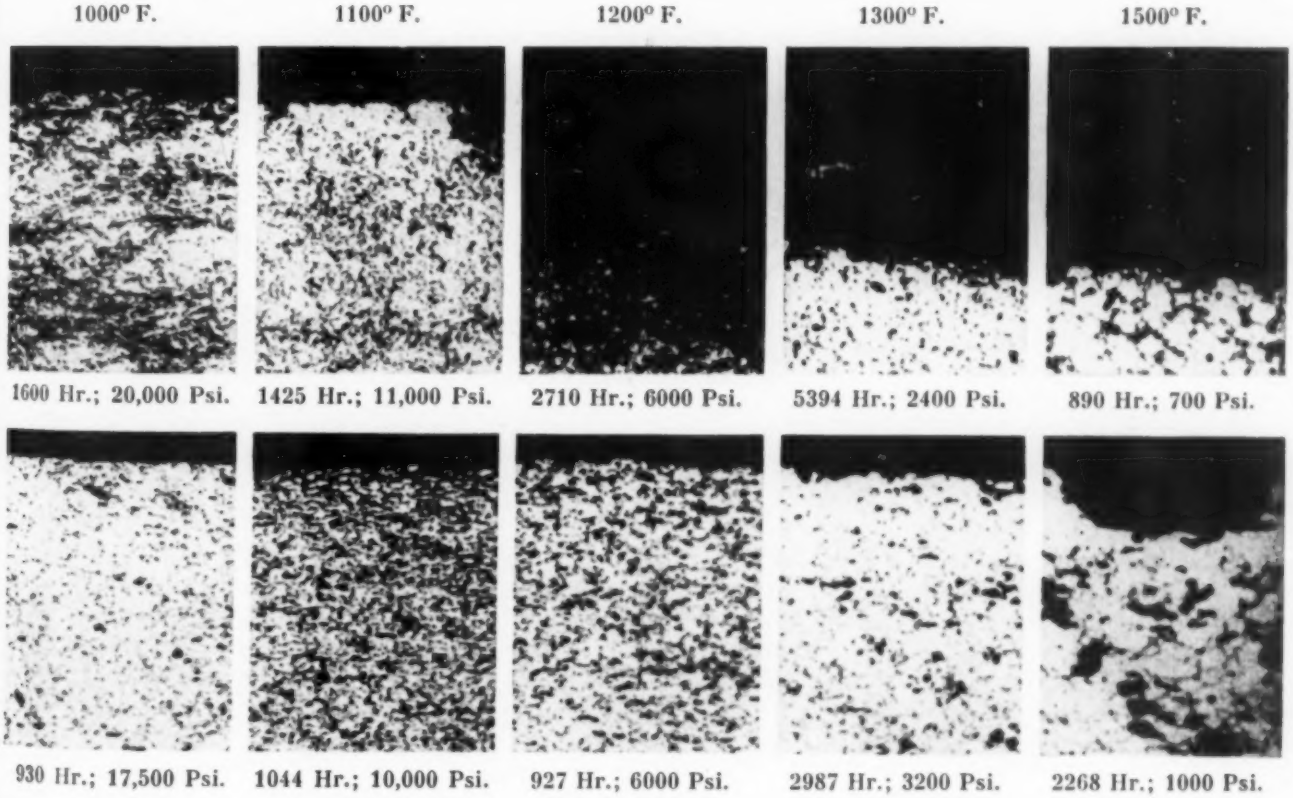


Fig. 7 — Influence of Time, Temperature, and Stress (Stress-Rupture Tests) on the Surface and Structural Stability of Two Steels of the 5% Cr, Mo Type. Top line for steel containing 0.18% Si; bottom line for steel containing 1.5% Si

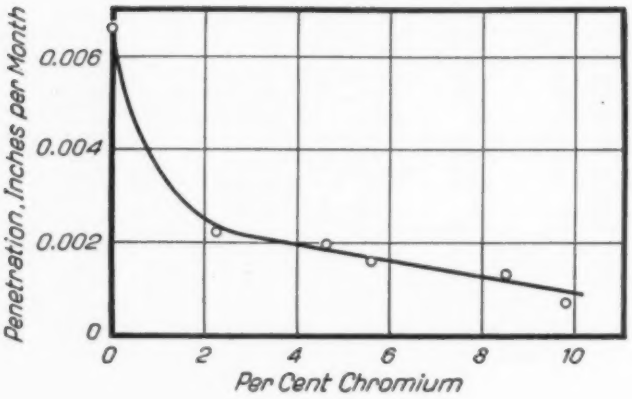


Fig. 8 — Relation of Corrosion Rate and Chromium Content of Steels When Handling Certain Corrosive Crudes at High Temperature and Pressure (Dixon)

especially in those applications in which oxidation or corrosion resistance is the prime requisite, but it is important that both the producer and user know what type of material they are handling.

Influence of Alloy Additions on High Temperature Properties

Now that the classification and quasi-equivalence of alloying elements have been considered, their influence on the high temperature properties can be considered. In general it may be stated that the solid solution alloys are most effective in improving the surface stability against either oxidation or corrosion while the carbide-forming elements are the most effective in increasing the strength. All of the elements of either group are not equally effective, however.

Solid Solution Elements — First, considering the question of surface stability and confining the discussion to oxidation, those solid solution alloying elements are effective which have a greater affinity for oxygen than does iron and which result in a dense and impermeable oxide layer strongly adhering to the surface of the steel. Maintenance of this protective layer depends on the diffusion of a sufficient supply of the alloying elements toward the surface so that the oxygen penetrating through the protective layer will be entirely consumed. The more common elements which fulfill these conditions are chromium, silicon and aluminum. Of these elements, silicon and aluminum are the more effective, provided chromium is also present, as shown in Fig. 6, page 901. In fact silicon appears to be seven times and aluminum four times as effective as chromium in chromium-bearing steels. The highly beneficial effect of silicon in this respect is likewise shown in the microstructures of Fig. 7.

The same general statements apply with respect to the corrosion resistance except that the alloying elements must have a greater affinity for the particular corroding agent than iron does. It is now generally agreed that resistance to corrosion in hot petroleum products is proportional to the chromium content, as shown in Fig. 8, which is taken from the work of E. S. Dixon mentioned in the opening paragraphs. More recent information shows the corrosion resistance to be more pronouncedly increased as the chromium is extended beyond 6.0% than he indicated. For example, results from one refinery show a 7.0% chromium type steel to be over five times as resistant as a 5% chromium steel, and a 9.0% chromium steel to be nearly 7 times as resistant.

Corrosion resistance in hot petroleum products can be further enhanced by adding silicon or aluminum. One refinery reports a steel containing 5.0% Cr, 0.50% Mo, 0.50% Al and 1.0% Si to be over three times as corrosion resistant as the standard 4 to 6% Cr-Mo steel, Type 502.

Carbide-forming elements which have been found most effective in improving the high temperature strength

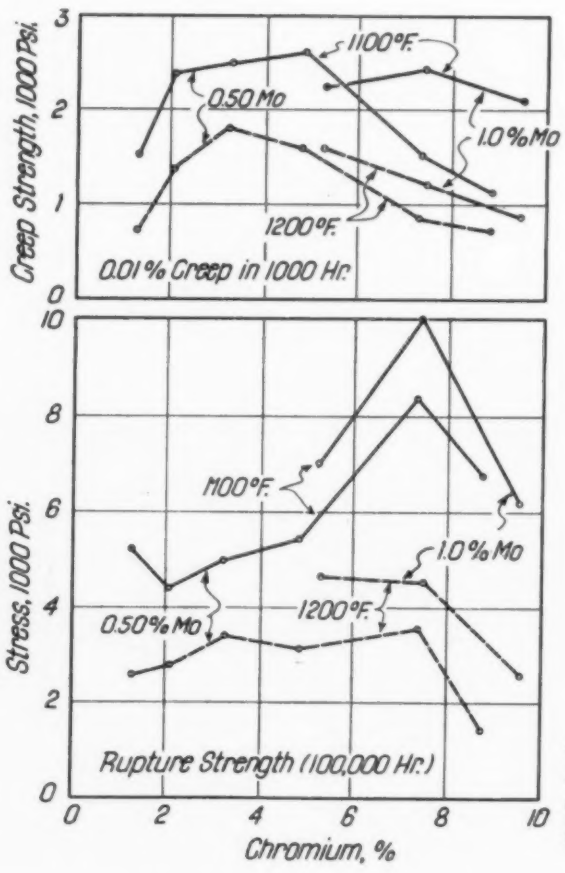


Fig. 9 — Influence of Chromium and Molybdenum Content on Creep Strength and Stress-Rupture of Steels Containing 1% Silicon at 1100 and 1200° F.

characteristics are chromium, molybdenum, tungsten and vanadium. Information is not yet as complete with respect to columbium and titanium, but data indicate both of these elements are also effective, provided an appropriate adjustment is made in the heat treatment. For example, the columbium and titanium modifications of 4 to 6 Cr-Mo, in a hot rolled and tempered condition, possess a superior creep resistance to annealed Type 502. When, however, all three are tested in the *annealed* condition, the creep resistance is of the same order of magnitude. This would indicate that modified structural characteristics, rather than the columbium or titanium addition, accounts for the increased strength.

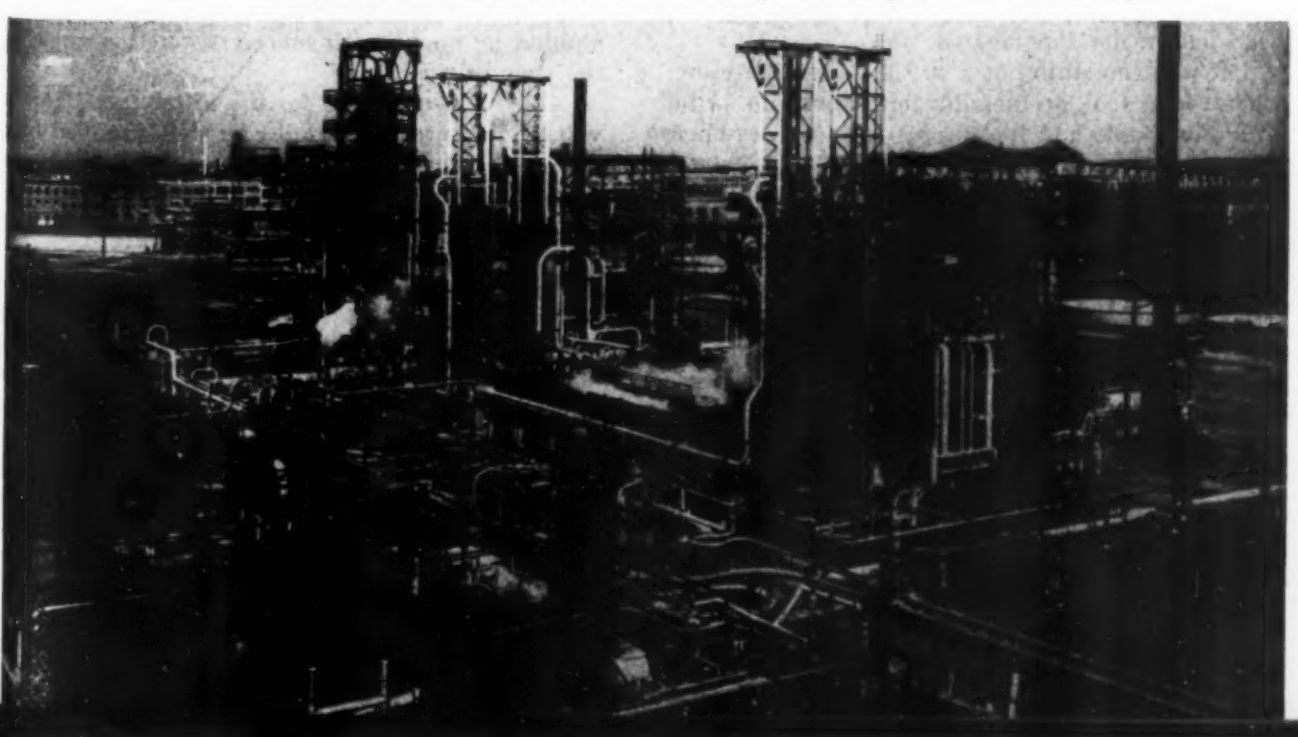
High temperature strength does not necessarily increase continuously with increasing additions of any of the carbide-forming elements; in most instances the maximum creep resistance corresponds to certain critical amounts. This is illustrated in Fig. 9 which shows the influence of varying chromium and molybdenum content on a series of steels containing approximately 1.0% silicon. At 1100 and 1200° F. the maximum creep strengths are obtained with chromium of about 5.0 and 3.0% respectively. In general, the strength is further improved by raising the molybdenum from 0.50 up to 1.0%, with the gains being the more pronounced the greater the chromium content. Other ferrite formers, such as vanadium, improve the strength provided they are not added in sufficient amounts to make the steel two-phased — but the improvement may not be sufficient to justify the alloy cost.

The fact that creep strength decreases as the chromium exceeds a certain amount should not imply that these higher alloy steels are unsatisfactory for high temperature service. Under conditions of severe oxidation or corrosion these higher chromium steels will actually have a better load-carrying ability than the lower alloyed ones, due to their greater surface stability. As previously stated, strength is only one of the criteria of actual load-carrying ability.

Evaluation of the load-carrying ability of the intermediate alloy steels is complicated by the fact that the laboratory results vary to a considerable extent depending on the rate of deformation used. This is also illustrated in the lower part of Fig. 9, which shows the 100,000-hr. rupture strength of the same steels. Under this very slow rate of deformation and in the presence of 0.50% molybdenum, the 7.0% chromium steel is superior at both 1100 and 1200° F. Increased molybdenum content likewise exerts a greater degree of improvement on the rupture strength at 100,000 hr. than on the creep strength.

The question therefore arises as to which characteristics should be used in the evaluation of the strength characteristics of these steels. In order to answer this the proposed application must be analyzed. If the application is one in which the temperature rises continuously during the operating cycle, as in cracking still tubes, and an appreciable deformation may occur over a relatively short time, then the rupture strength is believed to be the most suitable basis of evaluation. If, on the other hand, the temperature is constant and the permissible deformation small, then the creep characteristics can best serve for this purpose. A summary statement as to how the foregoing principles have been successfully applied to the development of alloy steels intermediate between the old 5% and 12% chromium steels will be presented in the next issue of *Metal Progress*.

A Modern Oil Refinery Consists Mostly of Steel Plate, Pipe and Shapes, Valves and Pumps



By J. D. Armour
Chief Metallurgist
Union Drawn Steel Division
Republic Steel Corp., Massillon, Ohio

Applications of Bessemer Bars Requiring Quality

Bessemer screw stock still maintains its superiority in the machining field, although metallurgists have been trying for years to equal its machining properties with steel made in the openhearth furnace and even in the electric furnace. In their efforts to equal the machinability of bessemer steel, they have added everything to openhearth steel they could think of, including fertilizer, and I do mean fertilizer. An old openhearth man said to me recently that he had been hearing about this "ferromanurium" for a long time but never expected to see the day when someone actually told him to put it in the steel.

Despite all these efforts, bessemer steel retains its superiority in the machining field, regardless of the fact that relatively little has been done to improve the machining properties of bessemer steel itself, except to keep raising the sulphur slightly from time to time as other steels attempted to encroach. This does not mean, by any means, that nothing more *can* be done, as I feel the possibilities of improving the machining properties of bessemer steel by intelligent metallurgical research are great, when and if we get crowded too closely by some of the future developments of openhearth free-machining steel. However, I do not believe I can get much argument on the subject of machining properties of bessemer steel, as I believe most people agree that, from a machining standpoint, it is a very superior steel, and there is not much danger of its being supplanted by openhearth merely from this angle in the near future.

In this symposium for the Pittsburgh Chapter will be presented other talks by well qualified men who will tell you some very unconventional processes that have been adapted to the bessemer converter. I will therefore not mention them further other than to emphasize that it is by no means necessary to operate a converter plant in the time-honored manner. Most users of steel (and many steel metallurgists, for that matter) believe that about the only thing that can be done is to bear down on the blast furnace man and make him give you a special iron; if the iron has too much sulphur and phosphorus in it, it is just too bad. The poor converter blower can't do anything to cure

I AM ALWAYS GLAD to have an opportunity to say a good word for bessemer steel. Bessemer steel and the bessemer process are probably the most maligned of anything in the steel business, and I have always resented such uncomplimentary remarks about bessemer steel as "the rottenest steel there is", and that it should be used only "when we do not care anything about strength or toughness". I probably came by my admiration for bessemer steel honestly, as my father was a steel blower in his younger days and all through my youth and later I heard him tell how satisfactorily bessemer steel could be made for parts such as street car rails, structural steel, and plate, and how it could be made hard enough to stand the wear and tear required for rails or soft enough to bend flat on itself as desired.

It was something of a shock to me, therefore, when I later took up metallurgical work and found so many people had the impression that bessemer steel was a very inferior product and its use should be avoided wherever possible and that it never should be used where any degree of toughness or resistance to shock were in any way involved. As my personal acquaintance with this outcast increased, I began to get the idea that maybe my Dad had something after all, and I finally became thoroughly convinced that there are a great many applications where bessemer steel is not only the equal of that made by other processes, but is decidedly superior. Perhaps the best example is in the field of machinability.

this situation. As a matter of fact the Wheeling Steel Corp. has made at least 1,000,000 tons of dephosphorized steel by a special bessemer practice and this method and the applications will be described in this symposium by C. M. Yocum of that company's staff [to be published in *Metal Progress* next month]. Likewise the National Tube Co. has made a great tonnage of fully killed steel in its bessemer plants, steel of such excellent forging quality it is used for the manufacture of seamless tubes. [See the article by E. C. Wright in last month's issue.]

Now let us consider some of the applications of bessemer steel that might shock those individuals who have been trained to think of it as a steel that should never be used if the service conditions are in any way severe. I have picked out only a few of the many applications of bar stock that illustrate how bessemer is successfully used for important applications and you can, no doubt, add many others to this list.

We might first consider the application of bessemer steel for bearings — yes, *bearings!* An application where bessemer steel is used as a bearing part is for bicycle coaster brakes and front wheel hubs. A bicycle hub is a carburized part and in addition to being the hub of the wheel, also forms the outer race of the ball bearing. These bearings must withstand quite severe service conditions. In addition to bicycle hubs, we also have bearings for roller conveyers and other applications where bearing pressures are light, where casehardened bessemer steel is successfully used for both cup and cone of the roller bearing.

Aside from casehardened bearings, bessemer steel is successfully used for a multitude of surface hardened parts. In fact, statistics show there is a greater tonnage of bessemer bar stock used for surface hardened parts than any other grade.

We might take up gears, as a further illustration. Bessemer steel is used for small casehardened gears in cash registers, adding machines and other types of business machines. In these applications bessemer steel is used because it makes the *best* gear, and not because it is the cheapest steel to use. The low core hardness obtained with bessemer steel for carburized parts ideally adapts it to small, fine-tooth gears. Under gears, we might also mention the small pinion gears which are used in clocks and many delicate timing mechanisms that require minute gears with a perfect finish on the teeth. Bessemer steel is also used for gear hubs for fiber or "micarta" gears.

Another application is hubs for belt pulleys for refrigerators, washing machines and similar equipment. In such uses, the hub must withstand a severe cold upsetting operation after the two sheet metal halves of the pulley are assembled with the hub.

Shotgun barrels and rifle barrels are uses of bessemer bar stock that might well shock those who have been educated to shun bessemer steel for important applications.

As an example of bessemer steel used for cold spinning operations, we have thimble stock in the textile industry which must withstand such forming operations without cracking.

An unusual application of bessemer steel is in type for typewriters and other business machines — used here because it will make a clearer-cut impression of the characters than any other steel.

We might add many other interesting parts to this list, such as radio loud speaker cores, sewing machine parts, shackle bolts for automobiles, and hydraulic brake hose couplings.

While at present the field of applications for parts made from bessemer steel bar stock is very large, I believe there are a great many others where bessemer steel could replace with advantage the steel now being used. Such changes of grade, of course, should not be made without careful study of the service requirements of the part and after consultation with the steel supplier.

I also believe there is much that can be done through research and investigation to improve the quality of bessemer steel and thus enlarge its field of application. Improved soundness might be obtained by a study of deoxidation practices. Improved impact properties might be obtained by such means as dephosphorizing. Improved impact properties on cold drawn bessemer bars can be obtained by stress relieving treatments or full annealing treatments after cold drawing. The effect of alloy additions to bessemer steel is also a field that has been touched only lightly, and it may have considerable possibilities. While some research work has already been done along these lines, undoubtedly much more will be done in years to come.

In summing up the case for bessemer bar stock, we would say the bessemer process is a quick, efficient and economical method of producing good quality steel. Its field of application is large at present, and there are many applications where it is to be desired in preference to other steels at any price. The field of application of bessemer steel can undoubtedly be greatly increased by intelligent metallurgical research. For these reasons, I feel the future of bessemer steel, as far as bar stock is concerned, is very secure. It will not only hold its own, but with proper development, it should increase substantially in the future.

Weldable High Strength Steel Castings

By Welton J. Crook*
Stanford University, Calif.
Formerly Colonel, Ordnance Dept. U. S. Army

DURING the war some extended studies were conducted at Rock Island Arsenal on the "weldability" of steel castings for gun carriage construction. Fortunately, we had lately investigated the factors governing the weldability, without preheat, of high strength plate used in carriages. This plate steel had a minimum yield strength of 70,000 psi. and, in addition, the only heat treatment possible was a stress relief treatment, after welding at 1000° F. Similar requirements were imposed on the steel castings. Preheating was frequently undesirable or impracticable; high physical requirements called for by Federal Specification QQ-S-681b included yield strength of 65,000 psi. or more. Castings procured to these specifications are ordinarily medium carbon (up to 0.40%), high in manganese (up to 1.40%), normalized or normalized and drawn. Serious cracking after welding was a common experience when such castings could not be preheated prior to welding.

Much of the cracking which may occur, when castings of high carbon and manganese content are welded without preheating, is of an insidious nature. The crack normally occurs beneath the dilution zone of the weld bead and unless this crack extends to the surface, its presence is not detectable by magnaflux, and infrequently by X-ray examination. Such a crack under the weld bead will often act as a nucleus for a progressive failure when the weldment is subjected to vibratory stresses.

In many weldments where castings are included, it is impractical to subject the assembly to any heat treatment more than a simple stress relief heating. This condition is present in gun carriage structures. The desired physical properties of the component castings must be developed by heat treatment *before* inclusion in the weldment, preferably by normalizing and drawing rather than by quenching and drawing.

This paper is a summary of some of the things we found out in investigating the problem thus briefly stated. It will supplement the information given in my article on "Weldable Steel Castings" published in *Journal* of the American Welding Society (Research Supplement), June 1944, page 257-S. It is hoped that the material presented will be of use to those making and using steel castings and also be of general interest to other metallurgists because of the numerous items of ferrous metallurgy involved.

Weldability — At the beginning it is necessary to agree upon the meaning of the term "weldable castings". According to the "Steel Castings Handbook" published by the Steel Founders' Society of America, a "readily weldable" casting is one with which only ordinary precautions must be taken before and after welding. This handbook also states that probably *all* steels are weldable and that the *degree* of weldability depends upon welding technique and procedures.

The American Society for Testing Materials does not define weldability but simply attempts to set certain limitations on the chemical composition, particularly on carbon and manganese, in castings which are to be welded. None of the A.S.T.M. specifications contain a test requirement for weld-

*The experimental work on which this paper is based was performed in the Laboratory Department, Rock Island Arsenal, and it is desired to express full acknowledgment for the assistance furnished by the metallurgical section of this laboratory. The cast steels were furnished by the Steel Casting Division, Rock Island Arsenal, and by various foundries, members of the Steel Founders' Society of America (cooperating through the office of Charles W. Briggs, technical and research director).

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ability and the highest minimum yield strength requirement is 55,000 psi.

From our experience with high strength plate, it was definitely known that the weldability of steel was governed by the carbon and manganese content (and to a lesser extent by the nickel content). A formula for estimating weldability had been developed and a test procedure adopted and set up. The formula is:

$$\text{B.H.N.} = \left[\left(C + \frac{Mn}{6}\right) + (Ni - 0.5)\ \ 0.06 \right] 1000$$

Where B.H.N. is the maximum weld hardness by Brinell test and wherein the contents of carbon, manganese and nickel are expressed in per cent.

The weldability test procedure was as follows:

1. **Test Plate:** 3x6x½ in.
2. **Weld Bead:** A single bead of weld metal, 3 in. long, shall be deposited by electric hand welding in the center and equidistant from the ends of the test plate. Electrodes shall be ⅛-in. diameter and have properties comparable to the finished heat treated properties of the plate tested. Procedure shall be with 200 amp., an arc voltage of 26, and rate of travel speed of 6 in. per min. Welding shall be done at room temperature, without preheat or postheat. During welding the plate shall be supported on an asbestos pad.
3. **Specimens:** At least three specimens shall be cut across the test plate normal to the bead, spaced from start and finish of weld. Sections shall be ground and polished for microexamination.
4. **Hardness Survey:** A hardness survey shall be made to determine the hardest spot beneath the weld bead, using Vickers or Rockwell machines.
5. **Maximum Weld Bead Hardness:** For plate steel, the maximum weld bead hardness shall be not over the equivalent of 300 Brinell hardness number.

There is no magic in the number 300 as a maximum hardness for plate steel. It was determined from a lot of experience that, when the limit of 300 was placed, weld beads did not crack.

Using the formula given above, a table can be computed giving the maximum manganese and carbon for given nickel contents, and this has been done in Table I, below.

Table I — Composition Limits of "Weldable" Steel

Manganese	Nickel	Maximum Carbon	
		Plate*	Castings†
0.45	0	0.225	0.375
0.50	0	0.215	0.367
0.60	0	0.200	0.350
0.70	0	0.183	0.333
0.80	0	0.167	0.317
0.50	1.0	0.187	0.337
0.60	1.0	0.170	0.320
0.70	1.0	0.150	0.300
0.80	1.0	0.137	0.287

*Maximum Brinell hardness 300.
†Maximum Brinell hardness 450.

A preliminary study disclosed that a maximum hardness of 450 Brinell could be tolerated for cast steel. This was exceedingly fortunate because the high strength castings had a yield strength of 70,000 psi. and this strength must be produced by normalizing and drawing and not by quenching and drawing. It must be carried in mind that, for a given chemical composition, considerably lower physical properties must be expected from cast steel than from rolled steel.

Carbon maxima for an allowable bead hardness of 450 in castings, also as computed from the formula, are given in Table I.

High strength castings are usually produced by relying on high carbon (up to 0.40%) and manganese up to about 1.40%. Such castings invariably cracked when welded without preheating. It is obvious that some alloy or alloys will have to be used, in addition to manganese and carbon, in order to meet high physical requirements and still retain weldability.

Outline of the Problem

The problem can now be outlined.

1. The castings must give a minimum yield point of about 70,000 psi.
2. The maximum weld bead hardness must not exceed 450 Brinell.
3. A minimum of alloys must be used, preferably obtained from residuals.
4. The physical properties must be developed by a normalize and draw.
5. The final draw temperature is to be 1000° F.

Some explanation should be given for the last two requirements. It has been found that when an "abnormal" steel (abnormal microstructure, as developed in the McQuaid-Ehn test for grain size) is normalized at a proper temperature and then drawn, a rise in yield strength will take place which reaches a maximum at about 1000° F. draw. When normalized and drawn steel of this type is subjected to welding, it is reasonable to suppose that less damage will result to the yield strength of the metal underlying the weld bead than would result if the casting had been previously quenched and drawn.

Experimental Heats

Keeping in mind the requirements of the problem and especially making use of the residuals in the scrap available, nine preliminary 5-ton acid electric heats were made. Keel block samples and weld bead test plates (Fig. 1) were poured.

Steel from these heats was subjected to three different heat treatments:

1. Normalize at 1700° F., draw at 1000° F.

2. Normalize at 1700° F., normalize at 1500° F., draw at 1000° F.

3. Normalize at 1700° F., oil quench from 1570° F., draw at 1000° F.

Average physical properties obtained from these tests showed that some were so low in carbon and alloys that the yield strength was below 65,000 psi. after any of the heat treatments. Considering the physical properties obtained by double normalize and draw, the yield strengths tend to vary with the amount of alloy other than carbon and manganese.

Four of the most likely looking are described in Table II. Figures printed in *italic type* are after treatment 1 noted above; figures printed in roman type are after treatment 2; figures printed in **bold face type** are after treatment 3.

The composition of these four experimental heats is substantially the same as far as the common (nonalloying) elements are concerned. Nickel ranges from 1.60 to 0.88; chromium is inversely proportional from 0.09 to 0.31; molybdenum is fairly high and variable.

No significant difference exists in the physical properties after treatments No. 1 and 2. In other words, double normalizing did not improve these four heats and generally would not warrant the cost of the second treatment.

Normalize, quench and draw did, however, strengthen the steels notably without too much damage to the figures for elongation (reduced 1/6 or less). Furthermore, the maximum weld bead hardness was unchanged.

On the basis of normalized yield strengths, the following is the relationship of these heats to alloy content:

Heat	Ni + Mo	Ni + Cr + Mo	Yield Strength
A	1.83%	1.92%	66,100 psi.
B	1.82	1.94	70,700
C	1.13	1.43	58,900
D	1.08	1.39	60,000

Production Heats, Weldable Castings

After considering the results obtained from all the experimental heats and taking into consideration the conservation of strategic alloys and the residuals obtainable from available scrap, it was decided to make a series of 15 production heats with about the following composition: 0.23% C, 0.65% Mn, 1.5% Ni, and 0.35% Mo.

Results of physical and weldability tests on these steels are grouped according to their general nature in Table iII. Nine heats in Group E were treated with 38 oz. of aluminum per ton; four in Group F were treated with 58 oz. of aluminum per ton. All were fine grained (8 or finer), abnormal, and consequently shallow hardening, except one of the first group which was rated 4 to 6. In addition there were two heats that were off average in composition in that one (Heat G) was high on nickel, manganese and silicon, whereas the other (Heat H) was high in carbon and manganese and low in nickel.

Table II — Data on Four Experimental Heats*

	Heat A	Heat B	Heat C	Heat D
Composition				
Carbon	0.22	0.23	0.22	0.22
Manganese	0.67	0.68	0.68	0.67
Phosphorus	0.026	0.024	0.028	0.030
Sulphur	0.026	0.026	0.025	0.026
Silicon	0.40	0.42	0.39	0.38
Nickel	1.60	1.44	1.01	0.88
Chromium	0.09	0.12	0.30	0.31
Molybdenum	0.23	0.38	0.12	0.20
Tensile strength	*84,600*	*94,000*	*81,400*	*82,600*
	87,000	93,500	83,000	83,700
	104,250	**116,000**	**91,000**	**100,500**
Yield strength	*66,100*	*70,700*	*58,900*	*59,500*
	67,250	72,000	61,000	60,000
	85,000	**96,500**	**73,400**	**77,400**
Elongation in 2 in.	*26.4*	*25.0*	*29.0*	*27.8*
	24.8	24.0	28.6	28.4
	21.3	**19.3**	**25.8**	**25.4**
Reduction of area	*52.6*	*51.0*	*53.7*	*50.8*
	51.0	50.6	52.8	53.4
	51.2	**49.1**	**49.1**	**49.0**
Brinell hardness	*172*	*199*	*170*	*175*
	183	196	170	175
	217	**248**	**202**	**212**
Maximum weld bead hardness	*404*	*411*	*366*	*362*
	404	411	366	362
	404	**411**	**366**	**362**

*Figures in *italic* are normalized and drawn; in roman type are double normalized and drawn; in bold face are normalized, quenched and drawn.

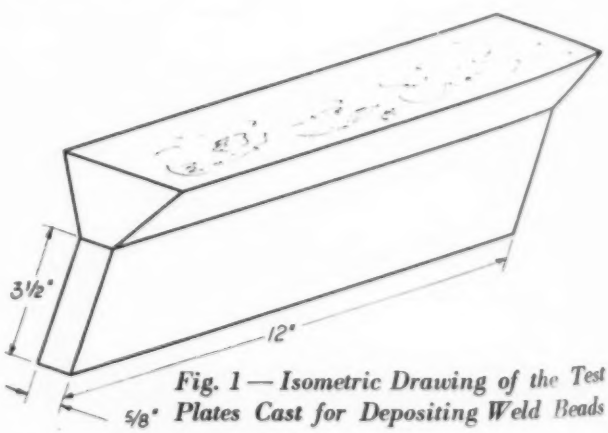


Fig. 1 — Isometric Drawing of the Test Plates Cast for Depositing Weld Beads

Table III — Data From 15 Production Heats*

	Group E	Group F	High Ni, Mn, Si	High C, Mn Low Ni
Composition				
Carbon	0.19 to 0.23	0.21 to 0.24	0.23	0.29
Manganese	0.56 to 0.68	0.60 to 0.69	0.70	0.78
Phosphorus	0.027 to 0.032	0.028 to 0.030	0.033	0.043
Sulphur	0.027 to 0.032	0.023 to 0.025	0.030	0.031
Silicon	0.30 to 0.48	0.37 to 0.41	0.53	0.41
Nickel	1.31 to 1.63	1.47 to 1.60	1.70	1.21
Chromium	0.06 to 0.08	0.03 to 0.08	0.12	0.12
Molybdenum	0.35 to 0.40	0.33 to 0.40	0.33	0.32
Copper	0.13 to 0.28	0.08 to 0.12	0.17	0.15
Tensile strength	*84,000 to 90,900*	*87,750 to 95,250*	*105,000*	*102,250*
	83,750 to 88,400	87,000 to 88,000	106,000	106,250
	104,000 to 110,600	**104,000 to 114,500**	**128,250**	**133,400**
Yield strength	*63,500 to 68,000*	*64,500 to 68,500*	*77,500*	*84,700*
	62,400 to 69,000	69,400 to 75,600	78,600	83,600
	77,900 to 90,000	**84,800 to 92,600**	**104,400**	**108,100**
Elongation in 2 in.	*20.9 to 26.0*	*23.8 to 26.2*	*21.7*	*21.0*
	23.9 to 28.0	24.4 to 27.3	20.0	15.8
	16.5 to 21.4	**17.2 to 19.4**	**15.4**	**12.6**
Reduction of area	*44.7 to 54.0*	*47.1 to 53.3*	*45.6*	*50.4*
	43.3 to 53.5	48.1 to 56.3	45.1	34.0
	33.0 to 53.0	**46.1 to 50.2**	**43.2**	**31.0**
Brinell hardness	*146 to 183*	*180 to 196*	*217*	*217*
	167 to 179	174 to 187	223	217
	212 to 230	**220 to 241**	**277**	**269**
Maximum weld bead hardness	*326 to 385*	*304 to 391*	*493*	*523*
	326 to 385	304 to 391	493	523
	326 to 385	**304 to 391**	**493**	**523**
Calculated bead hardness	359 to 389	382 to 401	422	462
Calculated hardenability	1.80 to 2.86	1.90 to 2.43	2.59	2.50

*Figures in *italic* are after normalizing 2 hr. at 1700 and drawing 4 hr. at 1000° F. Figures in roman type are after double normalizing (2 hr. each at 1700 and 1500° F.) and drawing 4 hr. at 1000° F. Figures in **bold face** are after normalizing 2 hr. at 1700° F., quenching from 1570 and drawing 2 hr. at 1000° F.

Average chemical composition of all heats in Group E and F was 0.22% carbon, 0.63% manganese, 0.38% silicon, 1.48% nickel, 0.06% chromium, 0.37% molybdenum and 0.14% copper.

The heats shown in the last two columns, higher in alloy, also possessed higher physicals than the average. However, advantage could not be taken of these higher physicals because the weld bead hardness exceeded the allowable limits of 450 Brinell, and weld cracks developed under the beads.

Comparison of the figures in the first two columns shows that the physicals of Group F steels treated with the larger quantity of aluminum are slightly better than those of Group E, at least in the normalized and drawn condition.

Preliminary Conclusion — As a result of the studies summarized above it was concluded that a steel composition of about 0.25 to 0.28% carbon, 0.60 to 0.70% manganese, 0.35 to 0.40% silicon, 1.40 to 1.60% nickel, and 0.30 to 0.35% molybdenum will consistently give yield strengths of from 65,000 to 70,000 psi. when normalized and drawn, and will have a weld bead hardness well below 450 Brinell. Such steels will be free from any tendency toward weld cracking when welded without preheating. When castings of this composition are oil quenched and drawn, a minimum yield strength of 80,000 psi. can be obtained. To insure a good reaction to the heat treatments, a McQuaid-Ehn grain size of at least 7 is desirable and the steel should be distinctly abnormal.

It is probable that other suitable compositions can be devised but our experimentation has shown that the carbon content should be limited to 0.30% max. with manganese of 0.75% max. With lower carbon, manganese may be increased to 0.85% but this figure should not be exceeded.

Tests on Commercial Steels

A survey was then made to obtain information on the physical properties, weldability without preheating, and other characteristics of steel castings produced by a number of commercial foundries to meet the requirements of Federal Specification QQ-S-681b.

Material for this study was secured through the Steel Founders' Society of America. We obtained 16 cast steel plates 6x3x1⅛ in. from each of 16 foundries representing 19 heats of steel. In addition, heats from Steel Casting Division of Rock Island Arsenal were included.

I will attempt to summarize the most important findings.

Chemical Composition — Each cooperating foundry furnished chemical analyses of their cast-

ings, and these were checked at the Arsenal. "Residuals" were determined spectrographically.

It was found that the steels could be divided into six general types as shown in Table IV; if one steel, of the C-Mn-V type, is neglected.

Physical Properties — The average physical properties, after 1700° F. normalize and 1000° F. draw, obtained from the steels in the six analysis types, are shown in Table VI. Although there are considerable variations in properties between individual steels in the various groups, as might be expected from the analysis spread, some idea of the effect of various additions may be gained.

When the average properties obtained from Types 1 and 2 are compared, it would appear that the use of the extra molybdenum in Type 2 is not justified. The highest tensile and yield strengths were obtained in Type 6 (C-Mn-Cr-Mo) steels, but this was at the expense of low elongation and reduction of area. The best average properties appear to be obtained in Type 5 (C-Ni-Mo), but entailed the use of about 1.3% nickel and 0.25% molybdenum. The next best properties were obtained in Type 3 (C-Mn-Mo). It appears to be difficult to obtain high yield strengths, 70,000 psi. or over, after normalizing and drawing, without the use of at least 0.20% molybdenum as an alloy.

One steel contained vanadium. This steel appears to give high yield strength with reasonable elongation by the substitution of 0.14% V for the 0.32% Mo used in Types 3 and 5.

Normalizing at 1700° F. was chosen as an average treatment suitable for the analyses concerned. The 1000° F. draw corresponded to the final stress relief treatment employed at Rock Island Arsenal for weldments containing steel castings (gun carriages).

Some steel showed distinct improvement in yield strength when double normalized and drawn (1700; 1500; 1000° F.). Others showed little or no improvement, while still others showed an actual decrease. There appeared to be no individual positive correlation between this change in yield strength and the normality or the McQuaid-Ehn grain size. However, those showing up best after a double normalize and draw had a low average grain size of about No. 3. Those showing slight or no raise in yield strength after the double normalize had an average grain size of No. 5.6 and those showing an actual decrease had an average grain size of No. 6.3.

It might be expected that the "normal" steels would show higher yield strengths when double normalized (with the second at 1500° F.) than they would with the single normalizing at 1700° F. However, this does not appear to be true. For instance, among those steels showing an actual decrease in yield strength with double normalizing, half were normal and half were abnormal.

Only five out of the 19 steels showed an increase in yield strength as a result of the extra normalizing treatment. There appears to be no correlation whatever between the effect of single and double normalizing and the composition types shown in Table IV.

Table IV — Composition Types, Commercial Steel Castings

Type	Class	Carbon	Manganese	Nickel	Chromium	Molybdenum	Copper
1	Carbon	0.21 to 0.35	0.71 to 1.66	0.12 to 0.17	0.05 to 0.23	0.02 to 0.11	0.10 to 0.22
2	C-Mo	0.21 to 0.32	0.50 to 0.96	0.07 to 0.36	0.04 to 0.10	0.15 to 0.47	0.11 to 0.69
3	C-Mn-Mo	0.24 to 0.30	1.07 to 1.51	0.10 to 0.20	0.04 to 0.10	0.19 to 0.49	0.09 to 0.33
4	C-Mn	0.26	1.34	0.22	0.08	0.12	0.16
5	C-Ni-Mo	0.23 to 0.31	0.58 to 0.90	1.28 to 1.38	0.06 to 0.12	0.27 to 0.37	0.15 to 0.28
6	C-Mn-Cr-Mo	0.25 to 0.44	1.17 to 1.59	0.10 to 13	0.25 to 0.84	0.20 to 0.46	0.11 to 0.15

Effect of single and double normalizing was compared in regard to yield strength because this physical property is, perhaps, the most important from a design point of view.

Weldability Tests — Standard weld bead tests were made on all steels, each steel being in three heat treated conditions: *(a)* Normalized at 1700° F. for 2 hr.; *(b)* normalized at 1700° F. for 2 hr. and drawn at 1000° F. for 4 hr.; *(c)* normalized at 1700° F. for 2 hr., normalized at 1500° F. for 2 hr. and drawn at 1000° F. for 4 hr.

Different steels exhibit their maximum bead hardness after different heat treatments. Thus, four steels were hardest after the single normalize without drawing; their maximum weld bead hardnesses were 452, 507, 514 and 537, respectively, an average of 502. Thirteen steels attained maximum weld bead hardness after normalizing and drawing; the range was considerably wider, individual figures being 300, 310, 375, 428, 453, 465, 478, 503, 510, 516, 537, 538 and 568, an average of 460. Six steels had hardest weld structure after double normalizing and drawing: 298, 397, 450, 475, 493, 562, an average of 466. Average analyses of these three groups were as shown in Table V.

Table V — Average Analyses of Steels Given Definite Heat Treatments

Element	Normalize	Normalize and Draw	Double Normalize and Draw
Carbon	0.28	0.28	0.31
Manganese	1.37	0.99	1.08
Phosphorus	0.034	0.035	0.038
Sulphur	0.027	0.032	0.033
Silicon	0.57	0.48	0.46
Nickel	0.17	0.15	0.12
Chromium	0.11	0.15	0.09
Molybdenum	0.37	0.24	0.18
Copper	0.21	0.18	0.14

From this limited number of steels it appears that the ones which showed their maximum bead hardness after a 1700° F. normalize have the greatest average maximum bead hardness, and those which required a double normalize (1700 and 1500° F.) and draw at 1000°F. to develop their maximum bead hardness have the lowest.

Likewise, the steels which showed their greatest maximum bead hardness after a 1700° F. normalize contained the highest average alloy content. However, there is no apparent correlation between the occurrence of maximum bead hardness as related to preliminary heat treatment, and the austenitic grain size nor degree of normality as revealed by McQuaid-Ehn test.

Cracking — When the steels were arranged in order of maximum weld bead hardness, it was seen that the first steel which had a root crack under the bead had an actual maximum bead hardness of 478 Brinell. The other steels which showed cracking had bead hardnesses of somewhat over 500. Experience has shown that a maximum bead hardness of over 450 cannot be tolerated, and the results of this survey verified experience.

Conclusions on Commercial Steels — A survey of the cast steels, produced by a number of representative foundries to meet the requirements of Federal specifications for high strength steel castings, showed that steels of at least six composition types are in general use. Where an average yield strength of 70,000 psi. or more was obtained after normalizing and drawing, the steels contained from 0.19 to 0.49% molybdenum.

Where the conditions of welding rule out any preheating, the more common types containing relatively high carbon (up to 0.40%) and high manganese (up to 1.60%) cannot be used because of inevitable cracking under the weld bead.

It appears that the use of molybdenum as a single alloying element is not justified. The best combination of high yie'd strength and low maximum weld bead hardness appears to be obtained in carbon-nickel-molybdenum types, especially where welding without preheat is desired.

Finally, the standard bead test for weldability appears to be reproducible and satisfactory.

Effect of Welding

This paper can be concluded with some information about the effect of welding on cast steel.

When we make a section through a weld bead, polish the section and apply a suitable etch and then examine the specimen at about 10 diameters magnification, we find three distinct zones — *(a)* what may be called the dilution zone, consisting of fused metal made up of the weld rod metal combined with some of the parent metal, and which is the part of the weld that has been actually molten; *(b)* underlying the dilution zone we find what may

Table VI — Average Properties of the Commercial Steel Castings
(Normalized 1700° F.; Drawn 1000° F.)

Type	Tensile Strength	Yield Strength	Elong. in 2 In.	Red. of Area	Brinell	Max. Bead Hardness
1	100,000	67,200	20.2	34.2	207	432
2	85,000	57,000	23.6	37.3	176	371
3	99,500	72,000	18.8	35.3	221	506
4	98,000	68,750	17.6	37.5	196	507
5	98,500	76,000	20.6	42.1	202	437
6	128,000	91,000	14.7	28.6	260	581

Fig. 2 — Plate With Single Weld Bead

A. Section to be scrapped.
B. Vickers hardness survey.
C. Tensile specimen.
D. Parent metal to be cut away by shaper.
E. Weld metal to be cut away by shaper.
F. Gage length of completely heat affected metal.

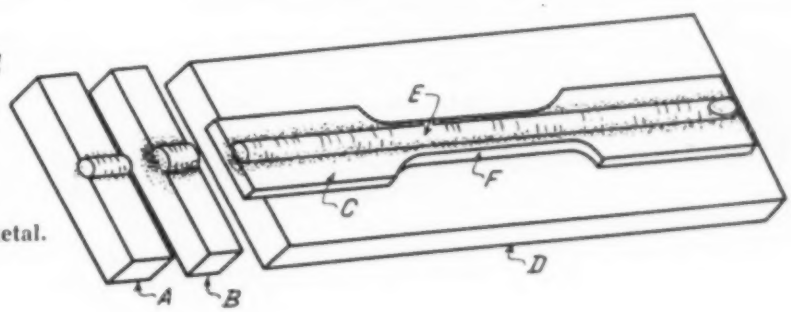


Fig. 3 — Vickers Hardness Survey of a Single Weld Bead on a Cast Steel Plate. Treatment: Normalized and welded. Magnification of sample, 6 diameters. Microstructure (750 diameters) of unaffected parent metal at left, of region of greatest hardness at right

be called the heat affected zone, wherein the metal has not been melted during welding but has been heated to a high temperature. This zone, under *constant* conditions of welding, such as voltage, amperage, speed of travel, will have a constant depth for a given steel but may have another depth for another steel. For instance, steels which are shown to be deep hardening steels by the Jominy test will have a deep heat affected zone; McQuaid-Ehn normal steels will also show a comparatively deep zone. On the other hand, aluminum treated, abnormal steels will show a comparatively shallow heat affected zone. Finally we have, beneath the "heat affected" zone, *(c)*, the unaffected parent metal which has not been heated above the lower transformation temperature.

In many actual weldments of plate steel, the heat affected zone may extend completely through the section, particularly where a weld bead is placed on both sides of the plate.

It becomes of interest, then, to determine what physical changes have taken place in this heat affected zone. In the past, numerous tests have been reported in which two specimens have been welded together and tensile specimens machined so that the weld metal and surrounding heat affected zone are located in the middle of the gage length. The results of tests on such pieces are influenced by the restraint (or lack of restraint) offered by the unaffected metal comprising the bulk of the test piece. In the tests which are now to be described the whole tensile specimen was located in the heat affected zone, without the presence of any weld metal or unaffected parent metal.

Welded Pieces Under Study

The weldability plate and the test pieces taken therefrom are sketched in Fig. 2. Similar samples were made in some instances with plates down which a double bead had been deposited, one on the top, one on the bottom directly underneath. Tensile tests in both varieties were cut so the gage length was of completely heat affected metal.

From a metallographic point of view, the condition of the metal in the heat affected zone is similar to that which would be produced if the steel had been very rapidly heated, as in flame hardening or induction hardening, to a very high temperature for a very short time and then rather drastically quenched (for instance, in water at room temperature). The time of heating is so short that there is little time for grain growth.

Material — The specimens consisted of cast steel plates, $\frac{5}{8}$ in. thick, $3\frac{1}{4}$ in. wide and 12 in. long. They were cast with heavy sink heads to

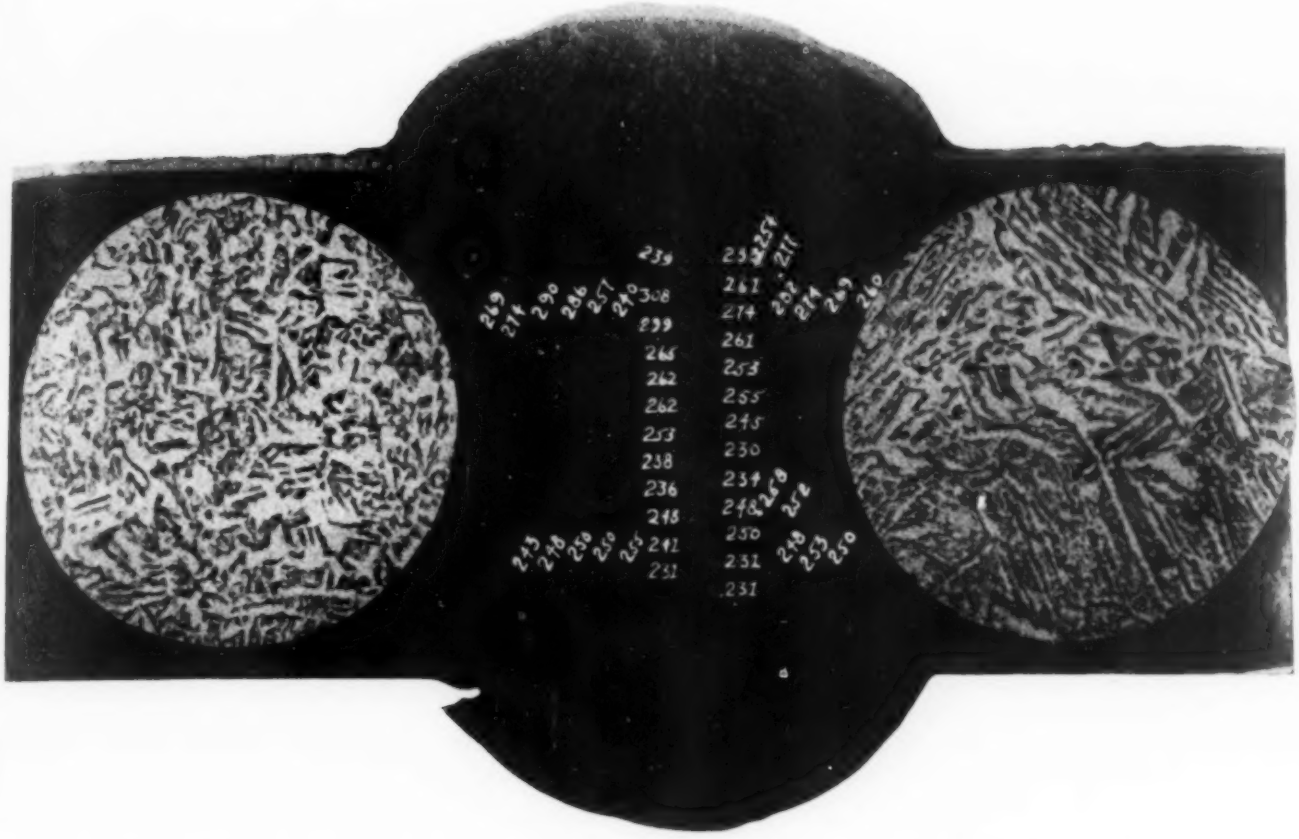


Fig. 4 — Vickers Hardness Survey of a Double Weld Bead on a Cast Steel Plate. Treatment: Normalized, oil quenched, drawn, welded, stress relieved. Magnification of sample, 6 diameters. Microstructure (750 diameters) of unaffected parent metal at left, of region of greatest hardness at right

assure freedom from porosity (Fig. 1, page 908). These plates were machined to ½ in. thickness and X-rayed; any showing porosity were discarded.

The composition was 0.20% C, 0.70% Mn, 0.030% P, 0.023% S, 0.45% Si, 1.46% Ni, trace Cr, 0.35% Mo, 0.06% Cu. This steel is of the "weldable" casting composition, as defined by the work described in the earlier sections of this paper.

Heat Treatment — When the weldable castings were developed, it was proposed to produce two types — *(a)* normalized and drawn, to give 70,000 psi. yield strength; *(b)* oil quenched and drawn, to give 80,000 psi. yield strength. It was desirable, therefore, to determine the effect of welding in the heat affected zone on parent cast steel which had been treated by these two methods of heat treatment preliminary to welding.

All test plates were given a preliminary normalizing treatment at 1700° F. They were then divided into three groups; two were given further treatment. The three groups are:

I. Preliminary normalize only: 1700° F. for 2 hr.
II. Preliminary normalize at 1700° F. for 2 hr.; temper at 1000° F. for 4 hr.
III. Preliminary normalize at 1700° F. for 2 hr.; oil quench from 1550° F.; temper at 1000° F. for 4 hr.

Tensile tests on these three groups are as follows (average of two tests):

	I	II	III
Tensile strength	94,150	91,850	111,550
Yield strength	59,350	63,900	89,000
Elongation in 2 in.	18.1	22.9	16.8

Welding — Weld beads were run of two varieties — on one set of plates a single bead was run on one side; on the second set of plates, a bead was run on both sides of the plate directly opposite each other. The beads were run with 200 amp., 26 volts, with a speed of 6 in. per min.

Effect of Welding Heat — Tensile test pieces were cut from the welded plates as shown in Fig. 2. Results are summarized in Table VII, showing the increase or decrease over the basic values listed.

Conclusions — A consideration of the experimental results reveals the following:

1. All actual weldments are finally stress relieved at 1000° F. In the single bead weld, the effect of this stress relief on the heat affected zone is to raise the yield strength about 3000 psi. and increase the elongation about 6%. In other words, stress relief restores the properties of the heat affected zone to that of the parent metal. However, it must be remembered that the steel tested is of such a composition that gives a low bead hardness.

Table VII — Increase or Decrease in Physical Properties, Heat Affected Zone Compared With Parent Metal

Condition of Casting	Stress Relieved	Bead	Tensile Strength	Yield Strength	Elongation in 2 In.
Normalized	No	Single	+6,700	+2,000	−3.6
Normalized	Yes	Single	−1,200	+5,000	+2.7
Normalized, oil quenched and drawn	No	Single	−2,000	−7,000	−4.2
Normalized, oil quenched and drawn	Yes	Single	−2,400	None	−3.3
Normalized	No	Double	+9,500	+13,800	−5.3
Normalized	Yes	Double	+3,500	+ 9,000	−2.9
Normalized, oil quenched and drawn	No	Double	−2,000	− 7,500	−4.1
Normalized, oil quenched and drawn	Yes	Double	−4,200	− 8,500	−1.0

With higher carbon and manganese, the effect might be different.

2. When the normalized casting is welded with a single bead and stress relieved at 1000° F., the heat affected zone is but little changed, as compared with the parent metal, except for a reduction in elongation of about 2%.

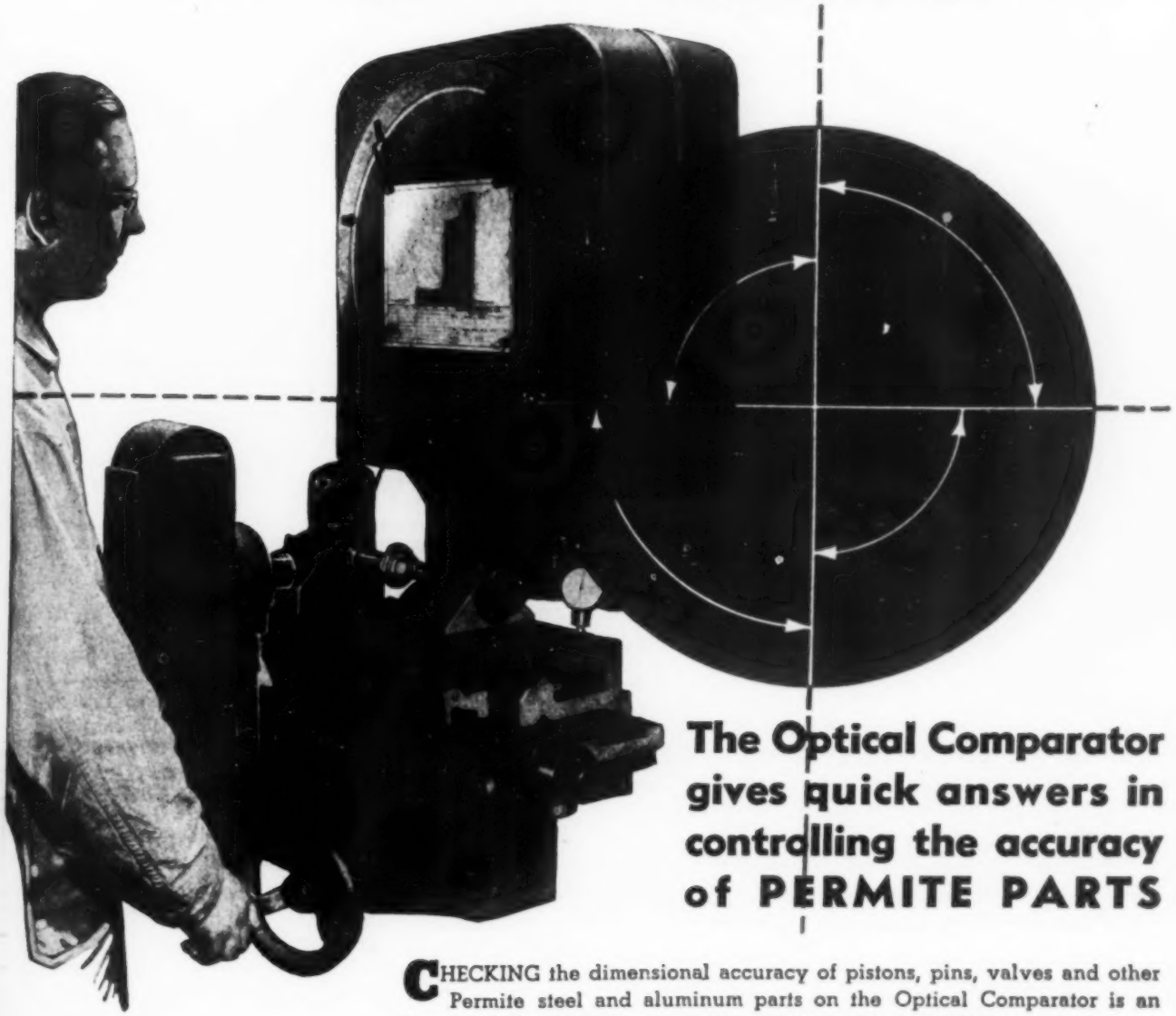
3. In oil quenched and tempered castings with a single bead, the heat affected zone, as compared with the parent metal, shows about the same tensile strength, a reduction of about 7000 psi. in yield strength, and a reduction of about 4% in elongation.

4. Where the heat affected zone may have received a double heating, with a double bead, the effect of the 1000° F. stress relief treatment is to decrease the tensile strength of the heat affected zone about 6000 psi. and decrease the yield strength about 5000 psi., but increase the elongation about 2.5%. However, as compared with the parent metal in the stress relieved condition, the properties of the heat affected zone, after stress relief, show an increase in tensile and yield strengths of about 6000 psi. and 4500 psi. respectively, with a decrease in elongation of about 7%.

5. In the case of normalized, oil quenched and drawn castings with a single bead weld, the effect of stress relief is to increase the yield strength of the heat affected zone about 8000 psi., and increase the elongation about 1%, the tensile strength remaining unchanged. With a double bead, stress relieving decreases the tensile strength about 12,000 psi., and increases the elongation about 3%, the yield strength remaining unaffected.

Photo Courtesy Lincoln Electric Co.

How right is a Right Angle?



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ALUMINUM PERMANENT MOLD, SAND and DIE CASTINGS...HARDENED, GROUND and FORGED STEEL PARTS

Selection of Die Castings

Relative Characteristics of Different Casting Methods

(Numbered in order of preference)

David Basch

Characteristic	Sand	Centrifugal (Metal Molds)	Permanent Mold	Die	Cold Chamber Pressure	Pressure Molded
Porosity	4	1★	2†	6	5	3 *(a)*
Surface	6	4†	5†	1	3	2
Sharpness of outline; tolerances	6	4†	5†	3	2	1
Strength (solid metal)	6	4★	5†	3	2	1
Thin section	6	4, as cast	5	3	2	1
Tool cost; pattern or molds *(b)*	1	2	3	4	5	6
Production speed and labor cost, per casting *(b)*	1 *(c)* 6 *(d)*	2 *(c)* 4 *(d)*	3 *(c)* 5 *(d)*	4 *(c)* 1 *(d)*	5 *(c)* 2 *(d)*	6 *(c)* 3 *(d)*
Possibility to save machining	6	4†	5	3	2	1

Notes: ★In metal left after removal of drossy material from inside of wall of straight centrifugal casting.

†Only in material next to metal mold.

(a) In critical sections.

(b) Tool costs and cost per casting depend on the number of patterns per plate or impressions in die; the more castings that can be made at one operation, the lower the labor cost per piece, with inversely increasing tool cost. Sand, plaster-of-paris and "investments" lend themselves more economically to multi-impressions than metal molds.

(c) On basis of most economical setup (as to number of impressions on one pattern plate or in one die) for comparative production quantities.

(d) For large production.

Order of Merit of Four Families of Die Castings

S. E. Maxon

Selection Factor	Zinc Alloys A.S.T.M. 21, 23, 25	Aluminum Alloys A.S.T.M. 5, 7, 12	Magnesium Alloys A.S.T.M. 12, 13	Copper Alloys (Brass)
Mechanical Properties				
Tensile strength	2	3	3	1 (strongest)
Impact strength	2	3	3	1 (toughest)
Elongation	2	4	3	1 (most ductile)
Dimensional stability	3 *(a)*	2	3	1 (most stable)
Resistance to cold flow	3	2	2	1 (most resistant)
Brinell hardness	2	3	3	1 (hardest)
Physical Constants				
Electrical conductivity	2	1 (highest)	3	2
Thermal conductivity	3	1 (highest)	4	2
Melting point *(b)*	1 (lowest)	2	2	3 (highest)
Weight, per cu.in.	3	2	1 (lightest)	4
Casting Characteristics				
Ease, speed of casting	1 (easiest)	2	2	3
Maximum feasible size	1	1	1	2
Complexity of shape	1	1	1	2
Dimensional accuracy	1 (most accurate)	2	2	3
Least section thickness	1 (thinnest)	2	2	3
Surface smoothness	1 (smoothest)	2	2	3
Cost				
Die cost *(c)*	1 (lowest)	2	2	3
Production cost	1 (lowest)	2	2	3
Machining cost	1	2	1	3
Finishing cost *(d)*	1 (lowest)	3	3	2
Cost per piece *(e)*	1 (lowest)	2	2	3
Extent of Use	1 (most used)	2	3	4

Notes: *(a)* A low temperature annealing virtually stabilizes Alloy 23 in dimensions.

(b) A low melting point is favorable in reducing die cost and upkeep and facilitates casting.

(c) Dies for casting the low melting point alloys are least expensive and have longest life.

(d) Includes polishing and buffing expense as well as ease of applying all types of commercial finishes, both electrodeposited and organic.

(e) Based on die, material and fuel costs, production speed, and machining and finishing costs.

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Salt Baths for Hardening High Speed*

THE CRITICAL PHASE of high speed steel hardening has always been the high-temperature operation. In order for salt baths to meet the requirements of this operation, two major developments have been necessary. First is the selection of a salt or mixture which will remain fluid and usable at the operating temperature, which is and remains inert to the steel surface, and which can be easily washed off the treated work. Second is the design and construction of pot-type furnaces which will hold the salt for a reasonably long life with a minimum of maintenance at the extremely high temperatures involved (2200 to 2400° F.).

Three chemical reactions may take place at high temperatures, namely, oxidation, carburization and decarburization. Most salts which are operable at the high temperature range have little tendency either to oxidize or carburize; in fact, they protect the work from oxidation by blanketing it against contact with the air. The main problem, then, is decarburization.

The earlier high-temperature baths were usually composed of fused borax or boric acid held in steel or iron containers, externally fuel fired. These baths prevented decarburization so long as they contained an optimum content of dissolved iron — which came mostly from the pot walls. When the iron content was too low, the work pitted and decarburized; when it was too high, the bath became viscous and inoperable, and even under the best of conditions some washing away of the work occurred and pot life was exceedingly short. This type of bath and furnace is now practically obsolete and will not be discussed further.

The modern high-temperature baths are basically anhydrous barium chloride ($BaCl_2$) contained in ceramic pots and heated by electrical resistance between two or more metal electrodes immersed in the molten salt. When freshly melted, this salt is inert to high speed steel surfaces and possesses the other necessary characteristics for high-temperature operation. After some time in use, however, the bath may become decarburizing due to the accumulation of soluble and insoluble metallic oxides. When this occurs, deoxidation (rectification) may be accomplished by methods to be described later.

Successful operation of high-temperature salt baths depends on maintaining the proper combination of furnace design and construction, salt composition, electrode material, method of rectification, and temperature control equipment.

Applications and Limitations

Molten salts are well adapted to the heat treatment of relatively small high speed steel parts such as cutting tools, gages, dies and machine parts. The operations of preheating, hardening, quenching and tempering may be performed conveniently and satisfactorily in salt baths of various compositions.

Cyanide baths now constitute the only commercially satisfactory method for producing a hard, wear resistant "nitride" case on finished high speed steel cutting tools without excessive brittleness. On the other hand, salt baths are not particularly applicable to large-scale heating in the manufacture of high speed steel bars and billets. Neither are they suitable for annealing machined parts if conventional slow cooling is necessary; such parts, however, can be successfully annealed isothermally by using two salt baths operating at the correct temperatures.

*One of the documents used by the Metals Handbook Committee in formulating the section on salt baths for the 1947 edition.

Many variables affect the relative merits of different types of heat treating equipment. However, for the benefit of the manufacturer who is considering whether or not to install salt bath furnaces, some of the outstanding considerations that apply particularly to high speed steel treatment are listed (not necessarily in the order of their importance).

Costs, both initial and operating, tend to run high, but comparison should be made on the basis of cost per pound of steel heat treated.

Productive capacity is very high in salt bath furnaces of proper construction; their output will be two to three times as much as other types of equipment of comparable size and heat input.

Distortion is very low. Methods of handling permitted by salt bath operation reduce distortion and rejects to a minimum.

Cleaning is fairly easy. Work which has been completely treated in salts has no scale. Most salts are easily removed by water washing. Some salts leave residues which may promote subsequent rusting or pitting, and this may require one or two extra pickling and rinsing operations.

Surface protection is very good. Work can be handled in properly controlled baths with no detrimental change in surface chemistry.

Safety — Molten salt baths constitute a natural hazard because of their susceptibility to explosion or spattering. Special precautions must be observed and men must be trained in the proper handling of work in molten baths.

Adaptability — Salt baths are better adapted to continuous or at least steady operation than to intermittent usage. Depending on construction and methods used for starting, they are more or less difficult to start up after shutdown. For most satisfactory and economical operation, they should be maintained molten at all times.

Temperature control is closer and more accurate than in other types of furnaces because of the heat transfer characteristics of the bath.

Equipment and Handling Methods

The complete heat treatment of high speed steel in salt baths requires separate furnaces for preheating, high heating, quenching, tempering and "nitriding". The high heat furnace should have a ceramic tile or brick-lined pot, either cylindrical or square, and as deep and narrow as possible in order to prevent heat losses through surface radiation. These furnaces should be heated with internal electrodes, either of the vertical immersed type or the horizontal submerged type. The most popular electrode materials are 28% chromium iron (A.I.S.I. Type 446), nichrome, Inconel, and pure nickel, although in special instances low-carbon steel and high speed steel have been used with fair success.

The preheat, quench, tempering, and nitriding furnaces may be of any conventional design so long as the following points are borne in mind:

1. Internal electrode heating is most economical and efficient.
2. Metal pots are satisfactory at these low temperatures.
3. Cyanides, fluorides, and carbonates are detrimental to the life of ordinary ceramic pots.
4. Nickel should not be used in the nitriding bath.

Since it takes longer to preheat work than it does to raise it to the temperature of the high heat, two preheat furnaces, each about the same size as the high heat, are desirable.

For best results, the heat input to all the furnaces should be automatically controlled by a good pyrometer. The exact type and make is a matter of individual preference. It is desirable, however, to have recording as well as indicating instruments on the more critical operations in the high heat, tempering, and nitriding furnaces. In all of the low-temperature operations, bimetal thermocouples enclosed in corrosion resistant protection tubes are satisfactory.

In the high heat bath, radiation-type thermocouples are preferred. These may be equipped with a closed-end target tube, made either of corrosion resistant metal or of ceramic material, immersed in the bath halfway to the bottom with the lens of the thermopile focused on the bottom of the tube. This system is accurate and durable and the replacement tubes are less costly than metallic couples. In other installations the radiation-type couple is equipped with an open-end tube which is sighted on the surface of the bath. If the surface of the bath is kept free of floating scum and cloudy vapors by blowing air down the tube and if the instrument is properly compensated and adjusted, the accuracy is generally sufficient, and there are no expendable parts.

Salt baths lend themselves well to handling small work in baskets. For best results it is recommended that the baskets be equipped with some means of separating individual pieces so they are not packed together in a tight mass. Long, slender parts, which may not need to be hardened over their full length, may be supported by set-screw or clamp-type fixtures so that the work hangs vertically in the bath. Other types of work may be wired, either singly or in groups, and suspended from long-handled hooks which can be laid across the top of the furnace. Some high-production fixtures which go through the high-temperature bath continuously are made of heat resisting

alloys, although usually cheaper materials, such as plain iron wire or low-carbon steel, make satisfactory work holders.

One of the greatest advantages in the use of salt baths for hardening high speed steel is the fact that the work can be supported so that a minimum of distorting stress is applied, both while it is in the bath and while it is being transported from one bath to another — a fact that tends to reduce greatly the amount of distortion experienced in hardening tools of delicate shape.

Where production is sufficiently high, it is possible to construct a conveyer system and completely mechanize the handling of parts through the preheat, high heat and quench operations.

Time-Temperature Cycles

In hardening high speed steel several baths are used in sequence and the salts should be so related that the carryover from one to the other will not be harmful. If in doubt, correct information should be obtained from salt manufacturers.

All baths should be desludged periodically by scraping the bottom with a long-handled, perforated ladle. Dry, powdered salt should be added as needed to maintain the bath-level. When rectifiers are used, desludging should be more frequent.

All furnaces should be kept molten insofar as possible. Overnight and week-ends the temperature is set at a point just above the melting temperature of the salt and the pot is covered. Very little energy is required to hold the baths in this condition.

Salt mixtures may be classified into nine types as shown in the tabulation below:

Type No.	Composition	Use
1	70% $BaCl_2$ + 30% KCl	Preheat
2	55% $BaCl_2$ + 25% KCl + 20% NaCl	Preheat or quench
3	95% $BaCl_2$ (min.) + 5% SiO_2 (max.)	High heat
4	95% $BaCl_2$ + 5% NaCl	High heat
5	20% NaCN + 40% NaCl + 40% Na_2CO_3	Quench
6	44% $NaNO_2$ + 56% KNO_3	Temper
7	21% NaCl + 31% $BaCl_2$ + 48% $CaCl_2$	Temper
8	44% NaCN + 32% Na_2CO_3 + 24% KCl	Nitride
9	40% KCN + 60% NaCN	Nitride

Preheat Bath — Either salt No. 1 or No. 2 may be used. Rectification is not usually necessary, but if desired small quantities of silicon carbide grain may be added periodically. The usual operating temperature is between 1500 and 1600° F. (A preliminary preheat at about 1200° F. is sometimes used.) A procedure that has proven advantageous on steady production consists of two preheats both operating at 1550° F. The two furnaces are kept loaded with four charges of work; when these have reached the preheat temperature, they are transferred to the high heat one at a time in rotation and new charges fed into the preheats. In this way, continuous production can be maintained as fast as the high heat can handle the work, with no waiting time between the two operations.

High Heat Bath — Either salt No. 3 or No. 4 may be used with advantage in a ceramic pot with internal electrodes.

In salt No. 3 the silica constitutes a deoxidizer.

The Heat Treater

Photo courtesy Ajax Electric Co.

Daily additions of about 5% of the salt mixture should keep the bath from decarburizing; if not, occasional small additions of silica flour may be made. This salt is generally heated by 28% chromium-iron electrodes; pure nickel or nickel alloys might give longer life but the nickel is more costly than chromium iron and, in a bath rectified by silica, nickel will be transferred from electrodes to the surface layers of the work. If nickel is used it is recommended that the silica content of the molten bath be reduced to 1 or 2%.

Salt No. 4 has several advantages. First, it has a lower melting point and lower viscosity, resulting in less drag-out. Second, it lends itself to rectification by use of a carbon rod, eliminating the use of silica. Third, because of the absence of silica, long electrode life may be obtained with nickel electrodes without depositing a layer of nickel on the surface of the work.

The exact method of rectifying with a carbon rod varies somewhat, depending on furnace construction. It is best to keep the rod completely submerged by placing it in special recesses in the pot walls; if more convenient, the rod may be immersed vertically and held by some clamping device above the top of the bath. With either method the rod should be removed periodically, cooled to room temperature, and the metal globules which it picks up scraped off. During this interval a fresh rod may be placed in the bath. The correct amount of time necessary to keep the rod in the bath is a debatable point. Some metallurgists say they have completely and successfully rectified a bath with only two or three 30-min. periods during the day, while others claim that the carbon rod should be kept in the bath all the time. One thing is certain — the rod or particles of carbon therefrom should not come in contact with the work or blistering will result. This combination of salt No. 4, plus pure nickel electrodes, plus a carbon rod for deoxidation, is the most recently publicized development in high heat baths and is rapidly gaining much popularity.

Hardening temperature depends on the grade of steel being treated. The control instrument should be set about 25 to 40° *lower* than in oven-type furnaces to get equivalent results because the work will actually come closer to the control temperature in salt baths than in gaseous atmospheres.

The work is usually brought just to the operating temperature and not soaked. Loads of moderate size, when immersed, will lower the temperature of the whole bath, and it is generally agreed that the work will become equalized with the salt temperature before the bath comes back to the control point. Therefore, it is customary to consider that when the control instrument throws off the power the work is at the operating temperature and ready to be quenched. (Very small loads may not cause a noticeable reaction either in the control instrument or the power input; proper timing for these will have to depend on the operator's judgment and trial-and-error methods.) Approximate timing cycles may be developed for repetitive work, but as electrodes wear down and as pot walls erode and salt volume increases, the time required to recover temperature will increase enough to require modification of the timing cycle. The best practice is to standardize the size of load and control timing by the moment of power shutoff.

Quenching Bath — Although moderately small work may be successfully hardened by quenching into oil or by cooling in still air from the high temperature, a molten salt bath is recommended on three counts — *(a)* to insure sufficiently rapid cooling through high temperature ranges for parts of any size, *(b)* to equalize the temperature throughout the part before cooling further (similar in principle to martempering), and *(c)* to wash off the barium chloride, which is not as soluble in water as most quenching salts.

Salts No. 2 and No. 5 are commonly used for quenching. Sometimes about 5 to 10% of sodium cyanide (NaCN) is added to salt No. 2. Its use is largely a matter of preference; it makes for easier washing and somewhat more fluidity at low temperatures. It also produces a file-hard carbon-nitride case about 0.002 to 0.003 in. deep on the work. Some proponents consider this to be good insurance that any soft surface due to decarburization in the high heat will be counteracted in the quench. Others believe such a case to be of doubtful value, especially on unground tools.

Quenching baths should be operated under 1200° F. with 1250 as an absolute maximum. The

maintenance of proper temperature is complicated by the fact that most suitable salts have a melting point of 1000° F. or higher when fresh, and this is raised as barium chloride is introduced. Consequently, the tendency is to raise the temperature to keep the older baths fluid. In baths containing cyanide, high temperature may form a crust on the surface by reaction with barium chloride. The remedy for this is *not* to raise the temperature further in an effort to melt the crust but rather to bail out salt, lower the temperature to 1150° F., maintaining the bath fluid at this temperature by dilution and frequent additions of fresh salt.

All quench baths accumulate considerable sludge. This should be removed frequently, else it will become caked and difficult to scoop out.

Time of holding work in the quench is usually about the same as the high-heat cycle. Each load should be removed before the next one is put in. It is recommended that work of normal size be cooled to room temperature from the quench by hanging in still air.

All work-holding devices that get into the quenching bath should be thoroughly washed *and dried* before going back into the preheat bath.

Tempering Bath — Either salt No. 6 or No. 7 may be used. Salt No. 6 is not recommended for temperatures much over 1100° F. because of the danger of severe oxidation of the work and the metal parts of the furnace.

If cyanide is present in the quenching bath, the work must be thoroughly washed before going into any nitrate mixture. It is good practice to wash and dry the work thoroughly before tempering, regardless of the salts used. On cooling to room temperature between the stages of multiple tempering, the work will be coated with a frozen layer of salt which will absorb moisture from the air; this necessitates drying by hot air blast before the work goes back into the tempering salt.

Tempering temperatures may vary between 1000 and 1200° F. depending on the hardness desired. Time of tempering is dependent on temperature and results desired, but in general should run about 1½ to 2 hr. total time for each tempering operation.

After tempering, the work should be air cooled to room temperature before washing off the salt in water. If calcium chloride is present in the salt, special precautions should be taken to guard against subsequent rusting. The first washing should be followed by a short pickle in an inhibited mineral acid or 10% acetic acid, plus one or two more rinsing operations, and a final dip in an alkaline cleaning solution.

Nitriding may be performed in any one of a variety of mixtures containing fairly large percentages of cyanide. Salts No. 8 and No. 9 are commonly used.

Nitriding baths are usually not very effective until they have aged by standing molten for a period of time. This may take anywhere from one day to one week, depending on conditions. Test pieces should occasionally be put through a fresh bath to determine when it begins to produce a file-hard surface, or analyses may be run to determine when the cyanate (CNO) content builds up to about 5% minimum. The bath should be operable at this stage and the cyanate content should be kept above 5% during operation by periodic bailing out and addition of fresh sodium cyanide or salt mixture. Occasionally it may be necessary to remove excess carbonate salts by cooling the bath to just above its melting point (about 850° F.) and scooping the precipitate out of the bottom.

The nitriding operation is usually performed on finished or nearly finished tools. The usual temperature is 1000 to 1050° F. and the time cycle may vary from 10 min. to 1½ hr., depending on type of tool and results desired. Its main function is to produce an extremely hard, wear resistant case on the ground surface, but it must be understood that this may cause some brittleness in tools of small size or delicate shape.*

Operation and Maintenance of Baths

Except for the high-temperature furnace, the operation and maintenance of salt baths for high speed steel heat treating does not differ from the operation of similar furnaces used for other purposes. In fact, in many plants the preheat, quench, and tempering furnaces may serve multiple purposes. The exact operating procedure depends on the type of construction and should be based on furnace manufacturer's recommendations plus a thorough understanding of the general hazards involved and precautionary measures necessary.

The ceramic-lined, internal-electrode type of high-temperature furnace does possess a few peculiarities of its own. In general, these furnaces are started with dry, powdered salt exactly the same as any electrode furnace, except that care must be exercised to avoid raising the temperature of the electrodes too high. Because of the high melting point of barium chloride, too much current may be applied before good circulation of the salt becomes established, sometimes melting the electrodes.

When a new furnace is started up, the ceramic pot will continue to absorb molten salt until it becomes saturated. It may sometimes take two or

*A complete discussion of the carburizing-nitriding baths was given by R. S. Komarnitsky in *Metal Progress* last month.

three days for the salt to seep through the brickwork far enough to freeze and seal itself. Until the sealing is complete, only silica-free barium chloride salt should be used, since sufficient silica will be absorbed from the brickwork — too much is detrimental both to the fluidity of the bath and to the stability of the electrodes.

Maintenance of the vertical immersed-electrode type of furnace consists mainly of checking and adjusting temperature control equipment, replacing electrodes, and keeping the bath properly deoxidized.

The lens of a radiation-type thermocouple should be wiped off at least once a day and the calibration checked two or three times a day by removing the head and sighting an optical pyrometer down the target tube. Failure of closed-end target tubes is indicated by a wide jagged line on the recorder.

Replacement of vertical electrodes depends on the temperatures used, the electrode material, and the condition of the salt. Failure may take place either through necking down at the air line or through gradual tapering below the surface. It is desirable to test the condition of electrodes by running a poker up and down their opposing faces periodically and to remove them before they are entirely gone so as to get replacements in before the bath freezes. Widening of the space between electrodes will necessitate an increase in transformer secondary voltage, otherwise too little current will enter to keep the bath hot enough.

Horizontal submerged electrodes cannot be replaced while the bath is in operation. However, under normal conditions, their life should be about equal to that of the brickwork so that, when they have finally deteriorated, the salt should be bailed out (if not frozen) and the entire inside of the furnace rebuilt with new electrodes in place.

The need for deoxidation of the bath may be determined by a number of simple tests. If a file test on pieces of work or test pieces which have been air cooled or oil quenched shows a soft surface, deoxidation (rectification) is necessary. A smooth, glassy sludge from the bottom of the pot shows that deoxidation is adequate while an ashy or pasty sludge indicates a need for more deoxidation. A crust on the surface of the bath indicates that an excessive amount of silica has been added and some salt should be removed and replaced with plain barium chloride.

Soluble barium oxide is considered the most active decarburizing agent and should be kept under 3% by adequate rectification. To determine the content of barium oxide, dissolve a 5-g. sample from the bath in water and filter. Titrate the filtrate with 0.1*N* hydrochloric acid using a phenolphthalein indicator. Calculate as BaO according to:

$$\frac{\text{cc. } 0.1N \text{ HCl} \times 0.00765}{5} \times 100 = \% \text{ BaO}$$

The insoluble metallic oxides of iron, chromium or nickel have a smaller decarburizing effect and are usually automatically kept under the safe maximum of about 5% by rectification based on the above test for barium oxide.

Table I — Equipment and Materials Required

	Preheat	High Heat	Quench
Furnaces	Steel pot	Ceramic pot	Steel pot
Size	14 x 20 in.	14 x 20 in.	14 x 20 in.
Power (single phase)	22 kw., 220 v.	48 kw., 220 v.	14 kw., 220 v.
Life of pots	2 yr.	1 yr.	3 yr.
Electrodes*			
Replacement length	24 in.	24 in.	24 in.
Weight	34 lb.	34 lb.	34 lb.
Working temperature	1550° F.	2325° F.	1150° F.
Average life	1 yr.	2½ weeks	2 yr.
Salt†	Salt No. 1	$BaCl_2 + SiO_2$	Salt No. 5
Daily additions	20 lb.	15 lb.	20 lb.

*Electrodes are 2-in. square bars of A.I.S.I. Type 446 chromium iron immersed vertically in each furnace.

†In this calculation 50% of the daily addition of high-heat salt has been added to cover the salt soaked up by a ceramic pot in starting.

Table II — Unit Costs

	Preheat	High Heat	Quench
Electricity	1.4¢ per kw-hr.	1.4¢ per kw-hr.	1.4¢ per kw-hr.
Material for replacement of pots and rebricking	$325	$275	$150
Electrodes	32¢ per lb.	32¢ per lb.	32¢ per lb.
Salt	14¢ per lb.	11¢ per lb.	15¢ per lb.

Table III — Cost per Working Hour
(Exclusive of Labor)

	Preheat	High Heat	Quench	Total
Salt	$0.35	$0.31	$0.375	$1.035
Current	0.95	0.80	0.210	1.960
Electrodes	0.016	0.17	0.004	0.190
Rebuilding	0.112	0.137	0.025	0.274
Total cost per working hour (four furnaces)				$3.459

Occasionally barium chromate, which is strongly decarburizing, builds up in badly neglected baths. Its presence is detected by a yellow or greenish-yellow color (or by chemical analysis), and it necessitates increased deoxidation.

Operating Cost Data

For a typical installation of four internal-electrode furnaces (two preheat, one high heat and one quench) handling continuous production, 40 hr. per week, the theoretical operating cost per working hour can be calculated, as in the tables.

With a four-furnace installation it is easily possible to harden 180 1-in. hand taps, weighing $\frac{2}{3}$ lb. each, per hr. (12 taps per heat and 4 min. per heat). Thus the operating cost of the furnaces for each tap equals 1.9¢.

The labor of handling the work and maintaining and rebuilding the furnaces has not been included. Extended shutdowns for repairs would also tend to increase the over-all cost per piece hardened.

As stated previously, it is probable that the optimum combination of salt, rectification, electrode material, and furnace construction would lower the electrode cost in the high-heat furnace, but even if this were zero, it would only mean a small reduction in the operating cost of the four furnaces, plus some saving in labor and downtime due to changing electrodes.

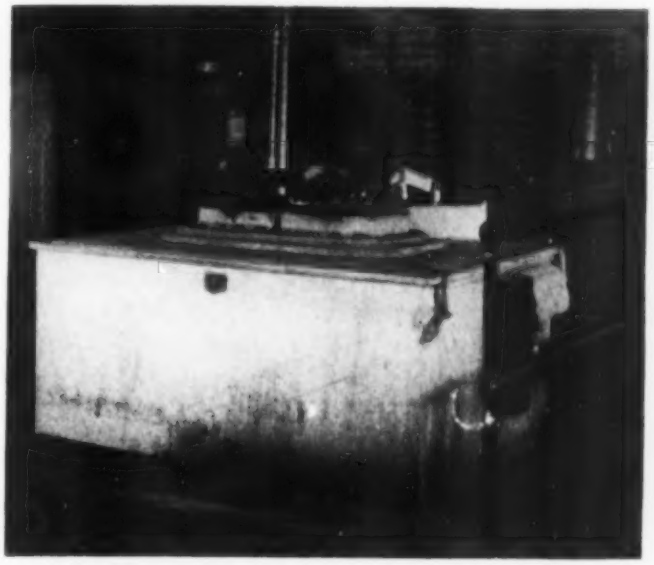
Summary

At the present time molten salt baths of the internal-electrode type are recognized as the most economical and generally satisfactory method for the heat treatment of high speed steel where continuous operation is feasible. Their main drawback is the difficulty of intermittent operation.

Therefore, those concerns which treat large quantities of high speed steel daily use salt baths almost exclusively for preheat, high heat, quench, and nitriding operations. Salts do not offer any particular technical advantage for tempering, and such use is a matter of individual preference even where salts are used for the hardening operations.

The smaller shops which have occasion to harden only a few tools at a time (perhaps once or twice a week) are, for the most part, still awaiting further developments in construction and operation of salt-bath furnaces which will better adapt them to their particular needs.

The sound principles which underlie the use of salt baths for the treatment of high speed steel will undoubtedly keep this process in the forefront of industrial popularity. There is, however, still room for improvement. Some new developments already in process hold promise of longer lived, easier operating furnaces, better control over decarburization, and more sensitive and accident-proof temperature control.



Electrically Heated, Automatically Controlled, Bath for Tempering Small High Speed Tools at Pratt & Whitney

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Much of the information presented in this article was obtained through private correspondence with users of salt baths as well as manufacturers of salts and furnaces. For more specific information, the reader is referred to the following publications:

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The Art of Quenching; I—Coolants

THERE is probably no operation in heat treatment which is of greater importance than quenching. Many of the valuable properties of metals, both ferrous and nonferrous, could not be realized without a good quenching operation in one form or another. In addition to the effects on physical properties, quenching procedures have important relations to variations in dimensional changes of heat treated parts and to subsequent physical operations such as machining, grinding, straightening and finishing.

It is the purpose of this discussion to consider quenching problems which arise in commercial heat treating shops or the closely related tool and die heat treating departments of industrial organizations, in contrast to those arising in the treatment of standard production items.

Commercial heat treating organizations differ essentially from production heat treating departments in that their work is of a widely variant character, day to day. Parts vary in size from instrument parts weighing less than one gram, to gears and machine tool frames weighing more than one ton.

Other factors which often complicate the commercial heat treating problem are: *(a)* Lack of a complete history of prior heat treatment and of fabrication of the parts; *(b)* limited knowledge of the function of parts treated, or the character of the materials to be formed or cut by the tools submitted for treatment; *(c)* limited control over design and selection of steels used in the parts; *(d)* lack of opportunity for experimentation, since the heat treatment procedures must be selected from past experience with similar items, and the first judgment of the heat treater is expected to be correct.

If the customer could supply complete information concerning the prior history and the expected functioning of parts, and cooperate closely with the steel supplier and the eventual user when designing the part and selecting the steel, many difficulties which occur in the quenching stage of heat treatment would vanish.

Historical—Many important observations were made by the early tool hardeners on the response of steels to quenching, without anyone being able to explain such behavior. More recent investigations into the mechanism of quenching, the critical cooling rates of various steels, dilatometric studies of steels during rapid cooling, cooling rates of the various quenching media, and the effects of surface conditions—all these have afforded means of explaining the causes of warpage, soft spots, dimensional changes and depth of hardening.

It is not surprising to find the early use of such peculiar quenchants as buttermilk, tan bark water, goat urine, imported waters and foul smelling fish oils, when we consider the difficulties which must have been experienced in quenching tools, dies, and machine parts made only of plain carbon steels of variable or unknown carbon contents. Attempts to control cooling rates by these odd quenchants were the forerunners of the discovery and use of modern quenchants such as brine and caustic solutions, molten metals, selected mineral oils, blends of mineral-animal oils, and the occasional use of emulsions.

"Time quenching" is by no means a recent discovery. Many an intricate reamer, milling cutter or blanking die of plain carbon steel has been spared the fate of cracking in quenching by the old-timer's quick quench (single or multiple) in water followed by a finishing quench in oil. This gave full hardness to the cutting edges and teeth with intermediate hardness in the heavier tool body, and minimum danger of protruding teeth

cracking, and "popping off" at junctions between thin and heavy sections.

Another early variation of the time quenching procedure was the use of a layer of mineral oil, three or four inches thick, floated on a water quenching bath. Intricate parts made of carbon steel were alternately quenched in the oil and water layers by rapid vertical movements. This resulted in a cooling rate intermediate between oil and water, which obtained full hardness.

Generations before dilatometric measurements studied the volume changes in steel on cooling, the heat treater was aware of the size changes and distortion to be expected. Through continued observations, practical means of controlling distortion were developed by cut and try methods.

Heat treatment of die blocks for drop hammers serves to illustrate this point. Plain carbon steel of 0.70 to 0.90% carbon was the ordinary material, and the usual heat treatment consisted of quenching the impression face of the die in water over a submerged water jet, allowing approximately half of the die to remain above the surface of the water, thus cooling in the air to obtain toughness in the shank. It was observed that after such a treatment the impression face often assumed a convex surface, and the shank end concave. It was found that much of this distortion could be eliminated by pouring a limited amount of water over the shank to "kill" the heat in this end to blackness while immersing the impression face in the water. During the quenching cycle water was dipped from the tank and poured over the shank at intervals, observing the flatness of the surface of the shank with a straight edge and applying water to various sections of the shank as it was needed to keep this surface flat.

It was sufficient for the early operator to know that such a procedure as this solved his problem; the academic reasons for the results were only of secondary importance. Today, the explanation seems quite simple, as is evident by consulting the studies of the effects of stresses during quenching as reported by Frank R. Palmer in his interesting book "Tool Steel Simplified".

Quenchants

The quenchants most commonly used in commercial heat treating plants are water, brine solutions, oils and air, but increasing numbers of applications are being found for molten salts, molten metals and occasionally emulsions of soluble oils and water.

Water and Brines — Ordinary city water finds wide use for quenching carbon steels ranging from 0.50 to as high as 1.20% carbon, as well as medium carbon, low alloy steels. Water, of course, is the most available and cheapest. It is easy to handle in quenching tanks and piping systems. Water is generally quite satisfactory if circulation around the work is adequate, to prevent visible boiling during the quench. Its temperature should not be over 100° F. at any time, as plain water loses its cooling speed rapidly above this temperature. One of the frequent difficulties encountered is the occurrence of soft spots on the work, due to the inability of the water quench to dislodge scale acquired during the heating cycle.

There is a growing tendency to substitute a 9% (by weight) sodium chloride brine solution (common salt) for water as a general quenchant for steels of the water hardening type. Over a period of years it has been found that more uniform hardening has been obtained with brine. While it is true that it is a faster quenching medium in the higher temperature ranges, it should not be concluded that the brine quench is generally a more drastic treatment than a water quench, and will cause a greater number of losses by cracking during the quenching period. Just the reverse is true. Water hardening toolsteels are more apt to crack when quenched in fresh water than when quenched in a salt brine. The brine solution contains less dissolved gases and therefore fewer gas bubbles attach themselves to the surface of the steel or form in recesses of the parts to cause soft spots. Brine also seems to be able to crack away the insulating furnace scale cleanly and thus get right down to the metal surface immediately.

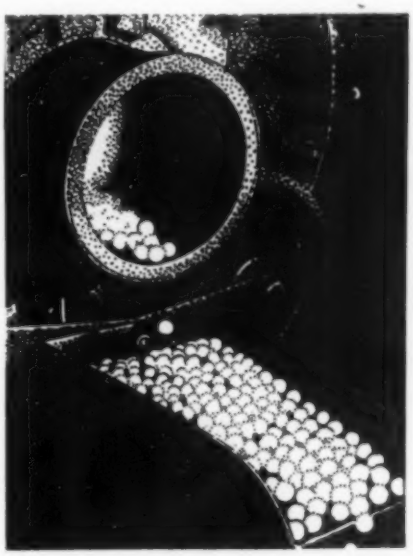

Figure 1 compares the center cooling rates of ½ x 2-in. cylinders of carbon toolsteel, in various portions of the cooling range, when quenched into various media at different temperatures. It will be noted that in the temperature range of 575 to 400° F. (300 to 200° C.) there is very little difference in the cooling rate of 5% sodium chloride brine and water at any temperature below 175° F. Since most water hardening steels show the greatest tendency

to crack when the temperature of work reaches 300° F. or below, these curves indicate that the brine solution would have no more harmful effect than clear water.

The use of sodium chloride brines is attended with some liability of corrosion of the work and the brine handling equipment. Rusty work can be prevented if the parts are promptly tempered after quenching and subsequently washed in clear water and alkaline cleaners when cool enough to handle.

principal oil companies and manufacturers of heat treating supplies. Oils meeting the following specifications have been found quite satisfactory for general quenching of bar stocks, machine tool parts, automotive parts and parts quenched from molten cyanide:

Gravity, A.P.I.	29 to 31
Flash point	360 to 380° F.
Fire point	410 to 430° F.
Carbon residue	0.01 to 0.04% by weight

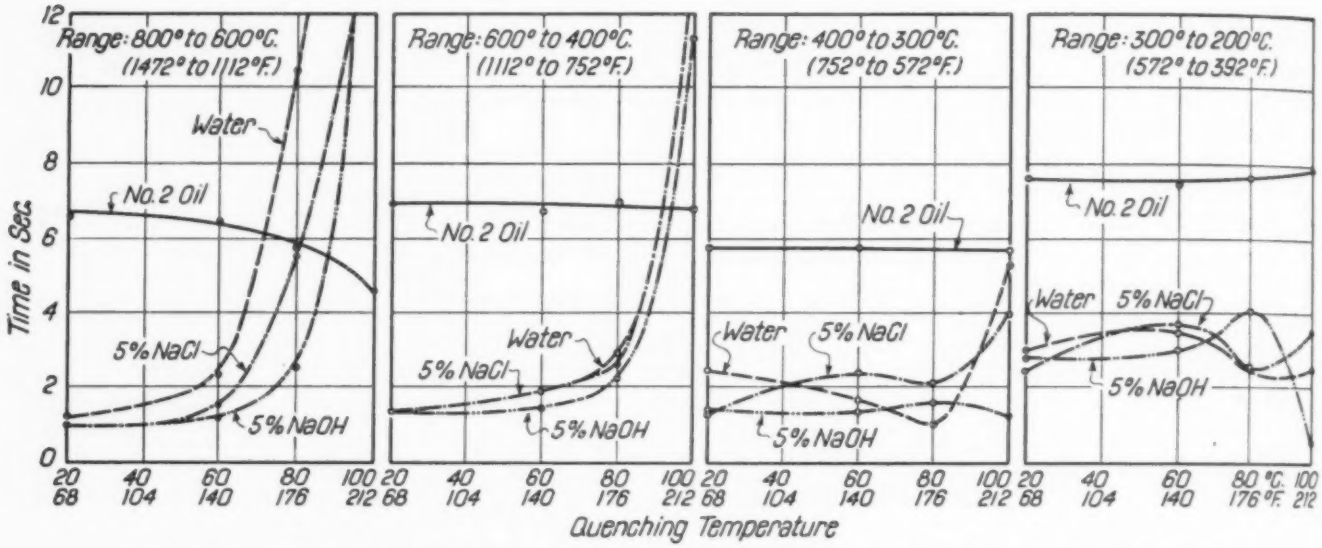
Range: 800° to 600°C. (1472° to 1112°F.)
Range: 600° to 400°C. (1112° to 752°F.)
Range: 400° to 300°C. (752° to 572°F.)
Range: 300° to 200°C. (572° to 392°F.)
Water
No. 2 Oil
5% NaCl
5% NaOH
Time in Sec.
Quenching Temperature

Fig. 1 — Time to Cool Through Various Intervals at Center of ½ x 2-In. Cylinder of 0.95% C Steel When Quenched From 1600° F. in Coolants at Various Temperatures. Coolant circulated at 3 ft. per sec. on surface of cylinder. Data from H. J. French and T. E. Hamil, Transactions *A.S.S.T., V. 16, 1929, p. 714, or "The Quenching of Steels", book by H. J. French, p. 114*

Prepared brine solution inhibitors are also available and they have reduced the corrosion of tanks, piping and circulating pumps to such an extent that the commercial use of brines as quenchants is practical.

10% calcium chloride brines and 5% sodium hydroxide solutions have been used as quenchants in production lines but are not recommended for general use by commercial heat treaters. The calcium chloride brines have no decided advantages over sodium chloride; on the other hand they leave a hygroscopic residue on the work which draws moisture from the air, causing rapid rusting. The sodium hydroxide solutions are efficient quenchants but attack the clothing of workmen and are a hazard to safety because of the possibility of being splashed into the eyes during quenching.

Quenching Oils — The quenching oils used in commercial heat treating are generally straight mineral oils made from paraffin base crudes. Numerous excellent oils of high stability and reliability have been placed on the market by the

Furthermore, the above oil, after the addition of 5% neutral lard oil, has been found to be a satisfactory quenching medium for oil hardening toolsteel and high speed steels. This compounding agent has no measurable effect on the center cooling rates of stainless steel cylinders, 2 in. diameter, 6 in. long, in the range from 1450 to 1200° F. It is the author's opinion that the sole advantage of adding small amounts of lard oil to mineral quenching oils, lies in the fact that it is more able to wet the steel surface uniformly, thus resulting in a better uniformity of surface hardness. Increased wetting power is possibly due to the formation of a very thin adherent deposit of carbon on the surface of steel soon after immersion in the oil.

In calculating the amount of oil required for a given amount of steel to be quenched, the oftenused rule of one gallon of oil per pound of steel quenched per hour is quite satisfactory. If the full pound per hour were quenched into an oil tank at room temperature, without circulation for cooling, the temperature of the oil at the end of the

first hour would be approximately 140° F., at which temperature the quenching rate of the oil is still uniform (see Fig. 1).

It has been found that some of the best results have been obtained with oil temperatures between 120 and 140° F. If a cooling system is used, the circulation should be adjusted to hold the temperature between 100 and 150° F. There is nothing to be gained by cooling the oil at any time below 80° F.; if it should fall to 50 or 60° F., due to week-end shutdown or winter weather, it is a good plan to warm the oil to at least 70° before quenching precision tools. This can be done by quenching dummy blocks of steels (if the quenching tank is small) or heating with steam coils. Cold oils do not yield maximum or uniform hardness because of their higher viscosity which interferes with free circulation around the work.

Molten Baths

Molten niter baths of the type commonly used for tempering, having a melting point of approximately 325° F., have been found invaluable in quenching intricate tools and dies of certain types of oil hardening steels, where it is necessary to maintain close dimensional tolerances or where the part has such a combination of heavy and light sections as to make even oil quenching a definite hazard. Oil hardening toolsteels having the following type analysis: Carbon 0.95%, manganese 1.20%, chromium 0.50%, tungsten 0.50%, vanadium 0.20%, reach full hardness when quenched from 1475° F. into a molten niter bath at 400° F. and then into oil as soon as the temperature has equalized. The amount of distortion resulting from this method of quenching is approximately one-half the amount after the direct oil quench, as measured by the Navy C-type specimen (Fig. 2).

To obtain the best results by quenching into hot niter it is desirable to heat the steel in a controlled atmosphere furnace, thus preventing scale. If such a furnace is not available the work may be packed in clean gray cast iron borings. Packing in carbonaceous materials is not recommended, inasmuch as some of it may be carried into the hot niter and cause a violent reaction. Molten niter baths are not recommended for steels requiring a quenching temperature over 1700° F. Hot work steels and oil hardening, high carbon, high chromium steels of intricate shapes may be quenched into neutral salt baths at 1050 to 1100° F. and subsequently quenched in oil after reaching the temperature of the salt bath.

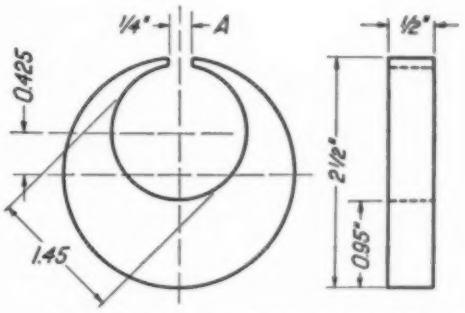

Fig. 2 — C-Type Gage, U.S. Navy Specification for Toolsteel 47S5c. Distortion is measured by comparing dimension A before and after quench

At present, it is not accurately known how many of the oil hardening toolsteels will respond with full hardness on quenching into molten niter at 375 to 400° F., but it has been found that the plain manganese, oil hardening toolsteels (0.90% carbon, 1.60% manganese, 0.25% silicon) and silico-manganese shock steels (0.50% carbon, 0.40% manganese, 1.00% silicon, 0.50% molybdenum) have critical cooling rates which are too fast to obtain full hardness by quenching into hot niter.

Molten lead baths are frequently used for the quenching of high speed steels of hazardous shape because of sharp re-entrant angles, or adjoining heavy and light sections. Many such intricately designed tools have been safely hardened by quenching from 2300 to 2350° F., holding in the lead bath until the part has uniformly assumed the temperature of the bath, and then quenching in oil (or even air cooling). The cooling rate of the molten lead is sufficiently rapid, in the range between 1300 to 900° F., that full hardness is obtained, even though the tool may be held in the lead bath up to an hour. Tools quenched in this manner must still be tempered, after they have cooled sufficiently to handle with the bare hands.

It has also been found that the above quenching method causes a minimum change in critical dimensions of such items as helical gear cutters, broaches, and long, dove-tailed tools. Appreciable camber of long, slender tools, such as line reamers and broaches, may be conveniently removed by supporting the tool in V-blocks and applying pressure to the high side, after the tool has been removed from the lead bath and while it is still hot — within the range of 500 to 900° F. In this stage of cooling complete transformation has not taken place and the steel is quite plastic, permitting considerable movement beyond the elastic range without danger of breaking.

A word of caution in regard to quenching into molten lead is in order: If for any reason it becomes necessary to anneal and reharden tools that have been quenched in a lead bath, it is essential that any adhering particles of metal be removed before the steel is reheated above 1400° F., else the surface will be severely pitted by adhering lead particles.

Automatic Heat Treating Machine

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PRODUCTION engineers, both in America and abroad, are re-examining heat treating operations not only from a cost angle but also their influence on labor relations. Instead of the dark, smoky atmosphere of the old-time shop, heat treating is being transferred to the production floor as part of the main production line. Furthermore, mechanization can be practically complete, eliminating the human element by making it possible for the least skilled to operate the unit successfully — in fact, the only labor required being that for loading and unloading trays.

These are conditions that have dictated the design of the automatic pusher type continuous heat treating furnace which is the subject of this brief article.

There are others. Electric heat was specified. Power costs are low in the region in Russia where it was ultimately set up. Electric heat also lent itself readily to automatic controls, a necessity, since skilled workmen were nonexistent. All heat and operating controls were set down in an automatic pattern so that definite, predictable results would follow.

These features readily were worked into a furnace which could be placed in any environment without objection from management or workers. Handling was reduced to a minimum by conveyers and hoists; heat and fumes were eliminated. Machined parts are fed into the furnace and removed 6½ hr. later at the other end, hardened, quenched and drawn ready for finish grinding.

The furnace was designed for small parts such as gear and sprocket blanks or tools and has a nominal output capacity of 750 to 1000 lb. of work per hr.

As shown by the accompanying views, work is transferred through all operations in trays, 16 by 20 in. in area. Each tray holds 165 lb. of material; the tray itself is of heat resisting alloy and weighs slightly less than 50 lb. Work is loaded manually on trays resting on the charging table, with the aid of an electric hoist and overhead monorail. The charging table (Fig. 1) consists of a pair of roller rails in alignment with the roller rails through the furnace.

The entire setup comprises two furnaces, separated by an oil quench tank and a washing machine. Over-all length is approximately 75 ft., each furnace having a hearth length of 16 ft. The hardening furnace has a maximum operating temperature of 1750° F., the draw furnace, normally operated at 750 to 1100° F., is similar in design to the hardening furnace, and on occasion can be operated clear up to 1750° F.

Each furnace is electrically heated by means of nickel-chromium ribbon elements, located along side walls and under the arch. Each furnace is divided into three heating zones; the first carries the highest rating to heat the cold work up to temperatures as rapidly as possible. Maximum input capacity for each furnace is 120 kw.

The hearth of each furnace comprises a pair of roller rails spaced approximately 12 in. apart and supported by brick piers capped with alloy castings. The roller rails are designed to permit free expansion and contraction without distortion.

Each furnace is enclosed in steel plate reinforced with structural shapes, welded gas tight, so prepared atmospheres can be used for bright hardening. All covers are provided with oil seals to guard against gas leakage. Likewise each vestibule is equipped with a steel plate door operating in channel guides and resting in sand or oil seals in closed position. Lining is high dielectric insulating refractory brick backed with insulating block.

Perhaps the most novel feature of this unit is

the equipment installed between the quench and draw furnaces. When the charging table pushes a tray of work into the hardening furnace, it automatically moves all the trays forward one position. This moves one tray onto the elevator, whereupon it is lowered into the quench tank. Work is submerged in less than 2 sec. after it leaves the hardening furnace, and since the elevator shaft passes through the floor of the furnace in the form of a cast alloy tube extending below the surface of the oil, this guarantees that the work will not come in contact with air before it is quenched. The quenching oil is constantly agitated by a circulating pump, and is cooled by water cooling pipes around the walls.

The quench tank includes two chain driven elevators which dovetail so that their platforms are parallel and level in the bottom position. One elevator brings the work down into the quench tank from the exit of the hardening furnace, and the other inclined elevator carries the same tray of work out of the tank at the other end to a position in front of the washing machine (Fig. 2).

The washing machine is of single station design. The work remains stationary and for the first time interval is sprayed with hot alkali to wash off the quenching oil. During the second interval, it is sprayed with hot rinse water to wash off the alkali. The tank at the bottom is divided longitudinally along the center line so that one compartment holds the hot alkali, while the opposite one contains hot rinse water. A tilting drain pan directs the over-spray and drain into the proper tank during each cycle. Each compartment is equipped with a centrifugal pump connected to its own set of spray nozzles, located both above and below the roller rails. Temperatures are maintained at 180° F. by immersion heaters; each tank requires approximately 30 kw.

Fig. 1 — General View From Charging End. Note motor driven hydraulic pump on pedestal, at right of each furnace, to operate doors and pushers

The quench tank elevators are driven through motorized speed reducers equipped with friction type slip clutches to permit overtravel of the speed reducer when the elevators have reached maximum position. This guarantees that the elevators will always be in proper alignment with the stationary roller rails onto which or from which the trays of work must pass.

Automatic sequence control is obtained through a combination of hydraulic and electrical equipment. Hydraulic pressure on the pushers is obtained from two motor-driven, self-unloading hydraulic pumps, one for each furnace. All hydraulic cylinders are operated through solenoid operated four-way control valves.

Control equipment is housed in a single cabinet containing all the necessary relays, timers, switches and fuses. A master timer, set for the production rate desired, starts the sequence control equipment which automatically resets itself upon completion of the cycle. The approximate steps in sequence are as follows:

1. Exit door of heat treating furnace and both doors of draw furnace move to the open position.
2. Pusher of draw furnace pushes a tray of work from the washing machine into the draw furnace, at the same time bringing a tray of work from the elevator platform into the washing machine. The quenching elevator moves up in the exit shaft to a position level with the floor of the heat treating furnace, while the other elevator moves down the incline to its bottom position.
3. Entrance door of heat treating furnace opens, and pusher moves tray of work inside, thus pushing all trays of work along one position.
4. Quench tank elevator lowers a fresh load of hot work into the oil, and both doors of heat treating furnace close.
5. After a time delay, sufficient to guarantee proper quenching, the inclined elevator brings the loaded tray up into position in front of the washing machine, the pusher of the draw furnace returns to its normal position, and the doors of the draw furnace close.

The entire operating cycle is completed in from 3 to 4 min., depending upon the time delay desired in the quenching tank. For a production rate of 750 lb. of work per hr., the master timer would be set to start one operating cycle every 13 min.

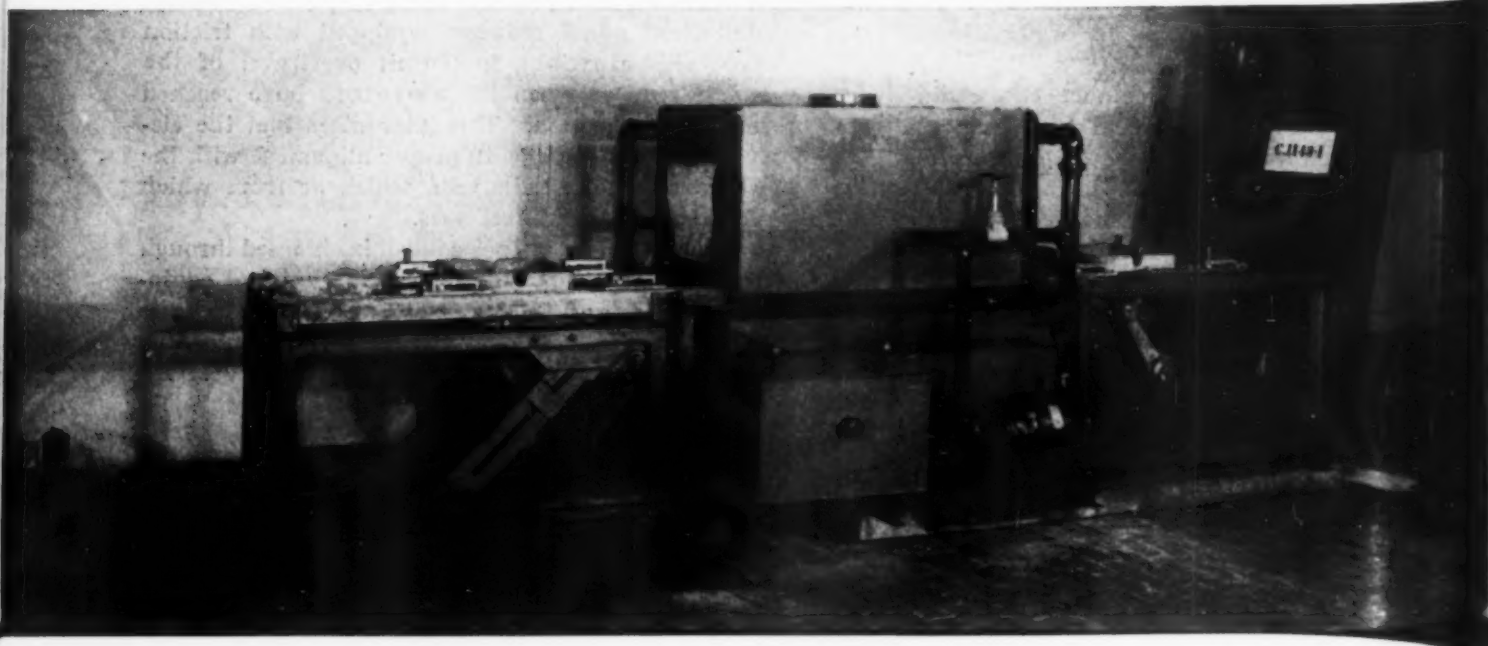
Beyond the exit vestibule of the draw furnace is a 10-ft. long collecting table with power driven rolls to move the trays beyond reach of the exit door after they have been pushed from the furnace. An electric eye counts the trays passing and also guarantees against closing the door before the tray gets into the clear.

BEFORE the war it was usual in Germany to produce surface hardened armor plates by carburizing, a well known but comparatively slow and uneconomical process, due to the time taken for the carbon to penetrate to the proper depth by diffusion. Large quantities of these plates would necessitate the erection of big plants for heat treatment alone.

Just prior to the war, the German Ordnance Department ordered the Dortmund-Hoerder Huttenverein to produce surface hardened armor plates, and to avoid high costs of the new carburizing equipment this company adopted the process of flame hardening with oxy-coal gas burners. They were successful in obtaining plates equal if not superior to carburized armor, in ranges about 30-mm. (1⅛-in.) thick. However, a hardened depth of 2 to 8 mm. (0.08 to 0.32 in.) could not be exceeded without overheating of the surface layers, and this limited the flame hardening process to armor plate of thicknesses below 50 mm. (2 in.) if satisfactory ballistic properties were to be obtained.

This thin hardened layer (say ¼ in. thick) on thicker plates for tanks, say 50 to 150 mm. (2 to 6 in.), gave no notable improvement in protection against heavier caliber projectiles over the same plate without flame hardened surface. As the German Navy was asking for plates of 200 and 300 mm. (8 and 12 in.) and even greater thick-

Fig. 2 — General View of Equipment Installed Between Quench and Draw Furnaces. Note inclined elevator from quench tank, washing and rinsing machine, pump for circulating solution (duplicate on other side) and pusher for draw furnace



Induction Hardening of Armor

By T. Bishop
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British Ministry of Supply

nesses, with a hardened layer approaching 100 mm. (4 in.) a new process was desirable.

Officials at Dortmund-Hoerder works saw the possibility of inductive eddy current heating, whereby the heat is generated in the plate itself, and applied for a patent for this heat treating method early in 1938.

As is well known, inductive heating — being very rapid — produces a hardened layer without scale formation, and with no effect on the unheated structure of the basic plate. Induction hardened armor is characterized by a homogeneous nodal martensite for a definite distance below the surface, with gradual transition into the sorbitic structure of the unaffected base. Surface hardness, usually a few points higher on the Vickers scale than obtained with flame methods, is maintained for approximately 80% of the depth heated, and gradually decreases from that point to the hardness of the original basic plate. The gradual transition of structure eliminates the chance of spalling or cracking between hardened face and unhardened back.

It was naturally desirable to heat the zone to be hardened as quickly and intensively as possible and, to avoid tempering the rest of the plate (which was in the usual armor condition — oil quenched and drawn), that portion had to be kept as cool as possible. The energy had to be introduced in the shortest possible time to prevent a heat flow from the heated zone to the cold portion of the thick plate.

The depth of the heated layer in the subsequently hardened zone depends principally on:

1. The power of the "high frequency" electrical generator.
2. The applied frequency.
3. The relative traveling speed between the induction device and the plate.

These three factors were varied with experimental models. In accordance with the theory, it was found that lower frequencies gave a deeper penetration. High frequencies (1000 or over) were not considered, as they produce only a skin effect of a fraction of an inch, as found in flame hardening. For the required deeper hardening zones, the frequency range of 500 or 600 cycles per sec. was found to be quite suitable, but experiments with lower frequencies were added.

As the public electricity supply operated at 50 cycles, it was thought that the use of that frequency, if only for plates of limited thickness, would avoid an expensive high frequency generator. Useful hardening results were obtained in the frequency range 40 to 150 cycles with appropriate power and traveling speeds. Any required depth from 10 to 70 mm. (⅜ to 2¾ in.) could be obtained with the experimental plates, 250 mm. (10 in.) thick.

In fractured test plates the hardened zone merges with the tough, heat treated zone with no noticeable demarcation line; only after etching can the exact depth be clearly seen. Vickers hardnesses, converted to tensile strengths according to German practice, show 270,000 psi. through the fully hardened surface zone, with easy transition (about equal in depth to the martensitic layer) to the unaffected backing at about 115,000 psi. Roland Wasmuht, chief metallurgist of the Dortmund group of plants, stated that the hardened layer is "very strong and resistant, and will not crack off on mechanical working and straining, in contrast to carburized armor".

Operating Plant

On the basis of these preliminary investigations, a bigger pilot plant was built. This will be described later, but at this stage it will suffice to describe the final arrangement of poles in the induction device. The shoe of the laminated iron core or pole was about 1x6-in. section, around which was six to eight turns of copper tube to carry the alternating current (of the order of 300

Mr. Molotov Discusses Bombs

ON October 29 the daily press carried a series of questions[1] submitted by HUGH BAILLIE, president of The United Press, and answers thereto by Premier J. V. STALIN of U.S.S.R. The following had to do with atomic bombs:

Question 26: Has Russia yet developed its atomic bomb or any similar weapon? *Reply:* No.

Question 27: What is your opinion of the atom bomb or a similar weapon as an instrument of warfare? *Reply:* I have already given my evaluation of the atom bomb in a known answer to Mr. WERTH. [Answering questions submitted by ALEXANDER WERTH, correspondent of "The Sunday Times" of London, Premier STALIN said, Sept. 24: "I do not consider the atom bomb to be a serious power, as certain political persons are wont to think. The atom bomb is meant to frighten the weak-nerved, but it cannot decide the fates of war since atomic bombs are by no means sufficient for this purpose. Certainly, the monopolistic possession of the secrets of the atomic bomb does create a threat, but at least two remedies exist against it: Monopolistic possession of the atomic bomb cannot last long and use of the atomic bomb will be prohibited."]

Question 28: How in your opinion can atomic power best be controlled? Should this control be created on an international basis, and to what extent should the powers sacrifice their sovereignty in the interest of making control effective? *Reply:* A strong international control is needed.

That same day Foreign Minister MOLOTOV of the U.S.S.R. addressed the General Assembly of the United Nations, saying among other things:

As we know, there are two different plans regarding the use of atomic energy. I have in mind the plan of the United States of America and the plan of the Soviet Union.

The American plan, so-called "the BARUCH plan," unfortunately is afflicted by a certain degree of selfishness. It is based on the desire to secure for the United States the monopolistic possession of the atomic bomb. At the same time, it calls for the earliest possible establishment of control over the production of atomic energy in all countries, giving to this control an appearance of international character, but, in fact, attempting to protect in a veiled form the monopolistic position of the United States in this field.[2] It is obvious that projects of this kind are unacceptable. . . . . This plan, moreover, is afflicted by certain illusions.

Even in the field of atomic energy one cannot possibly count on the monopolistic position of any single country. Science and scientists cannot be put in a box and kept under lock and key. It is high time that illusions on this score were discarded. Illusionary are also the hopes for a decisive effect of the atomic bomb in time of war. It is common knowledge that the atomic bomb was used against cities; it was nowhere used to deal with troops. And this is not an accident.

If there are, however, plans to use atomic bombs against the civilian population of cities and to use them on a large scale at that, as certain of the newspapers babble, one should not give oneself up to any illusions with regard to the international effect which will be produced by the realization of atrocious plans of this kind. Justified resentment may entail political consequences which will mean the greatest disillusionment, above all to the authors of those plans.

Lastly, it should not be forgotten that atomic bombs used by one side may be opposed by atomic bombs and something else from the other side and then the obvious collapse of all present-day calculations of certain conceited but shortwitted people will become all too apparent. . . . .

There is a different plan for the atomic bomb, the plan suggested by the Soviet Union.[3] This plan is based on entirely different lines.

We, the Soviet people, do not tie up our calculations for the future with the use of the atomic bomb. I would recall that the General Assembly has already declared for the exclusion of atomic weapons from national armaments. Therefore, there is no reason to postpone the adoption of an international convention proposed by the Soviet Union regarding the banning of the manufacture and use of atomic weapons. Only by adopting such a decision will we create conditions favorable to a free and fruitful examination of the questions relating to the establishment of control over atomic energy in all countries.

It was after the first World War that the nations reached agreement to prohibit the use for military purposes of poisonous gases, bacteriological means of warfare and other inhuman implements of war. It is all the more necessary to prohibit the use for military purposes of atomic bombs or other means of mass annihilation. . . . .

The honor and conscience of freedom-loving people demand that the atomic bomb be outlawed, for the United Nations will never assume the responsibility for any plans to use atomic energy for the purpose of wholesale destruction of people and in general to use it to the detriment of mankind. . . . .

The Soviet delegation submits for the consideration of the General Assembly the following proposal:

1. In the interests of consolidating international peace and security and in conformity with the purposes and principles of the United Nations organization the General Assembly considers a general reduction of armaments necessary.

2. The implementation of the decision on the reduction of armaments should include as a primary objective the banning of the manufacture and use of atomic energy for military purposes.

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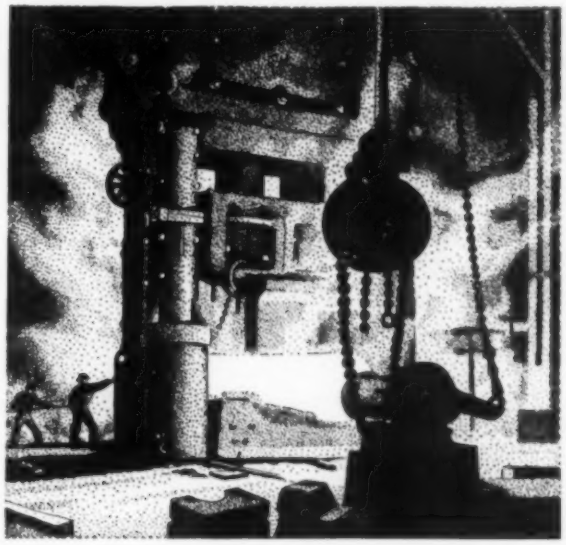
[1]Copyrighted by The United Press. [2]The proposals of the United States government to the United Nations' Atomic Energy Commission, made through BERNARD M. BARUCH, follow closely the LILIENTHAL committee's report on international control, outlined in *Metal Progress* in May, p. 992. [3]Outlined in the July issue, page 83.

amp.). The tube was water cooled. The coil was wound in one plane, with lower surface flush with the end of the pole, except that the outer one or two turns were refused slightly to allow clearance for the water jets to quench the hot plate as soon as possible.

The coil itself contains impregnated paper insulation between turns, and covers an oval area about 14x34 in. Six of these poles and coils, placed side by side, therefore cover a 7-ft. wide plate for about 3 ft.



This group of poles and coils are held above the plate to be hardened by a device which can be oscillated laterally for 3 or 4 in. if desired; it also travels over the length of the plate, and can be raised and lowered. The whole layout can be compared to the normal planing machine, with the poles attached to the tool crosshead, the crosshead itself being a gantry running on rails at either side of the fixed bed.

The equipment is kept universal in order to cover all variables, and it can surface harden armor plates 7 ft. wide and 24 ft. long of any desired thickness up to 600 mm. (24 in.). The variables are covered as follows:

1. Frequency: *(a)* 50 cycles (the frequency of the public circuit); *(b)* 500 cycles (from an 1800-kw. high frequency, single phase generator).
2. Different arrangement of inductors: *(a)* Poles with length parallel to the traveling direction; *(b)* Poles at right angles (across the narrow dimension of the plate).
3. Movement of the induction device (pole groups and coils): *(a)* Stationary in respect to supporting gantry; *(b)* Oscillating.
4. Adaptability of inducting device, as it moves along the plate: *(a)* The angle between the inducting device and its traveling direction can be varied; *(b)* The angle between plate and inducting device can be varied vertically to the traveling direction, for hardening tapered plates such as are sometimes required in naval practice.
5. Variation of the air gap between the plate and inductors (say ¼ in. to 1 ft. or more).
6. Variation of the traveling speed (1 to 8 in. per min.).

Strong vibrations were feared as a result of the magnetic field, especially with the 50-cycle frequency. It was therefore decided to clamp the plate to a heavy base. Vibrations were not so bad as were expected, however, and holding was no problem for thick plates.

Heating and subsequent quenching took place in a zone progressing from one end of the plate to the other according to the traveling of the overhead structure, which carries the inducting device. Quenching was done by jets of "normal" water, and the plate and base to which it was held were sloped at about 10° to the horizontal, to drain in the opposite direction to the gantry travel.

The transformers for both the 50 and 500 cycles were attached to the overhead structure and so traveled along above the plate. The electrical equipment, which with the rest of the apparatus has been sent to the Naval Ordnance Laboratory at Indian Head, Maryland, consists principally of a high frequency motor-generator (rotating type) of orthodox design, separately excited, and feeding current to transformers via a special reactor and thence to the induction heating coils. Each inductor coil has its own transformer and separate set of controls. The gantry also has three 50-cycle transformers connected direct to the 6000-volt power lines. Electricity and water supplies to the movable gantry crane come via flexible leads and hoses from towers on each side of the base plate, at midlength.

Data indicate that the relationship between depth of hardness and electrical input is proportional to the speed of travel. For example, on plates 2½ to 4 in. thick, travel 6¾ in. per min., 600 kw. of power will harden 0.35 in. deep, whereas 800 kw. of power will harden 0.60 in. deep. (Intermediate power inputs will give proportionally deep hardnesses.) When traveling at 4 in. per min., 500 kw. of power will harden 0.45 in. deep, whereas 800 kw. of power will harden 0.90 in. deep. When traveling as slow as 2.4 in. per min., 400 kw. of power hardens 0.80 in. deep, and 600 kw. 1.25 in. deep.

When the poles were at right angles to the traveling direction the transition between hardened and unhardened zones was a plane. However the hardened zone was only as wide as the

coil, and there is a limit to this width. Wide plates would be hardened in two passes, and the overlap at center would cause some metallographic discontinuities.

On the other hand, when poles are parallel to traveling direction, the hardening zone was wavy-limited. This wavy-limit can be avoided if the inducting system is lined up diagonally across the plate, at an acute angle to the direction of travel. However, the slightly wavy or corrugated transitional surface may not be undesirable.

Using 50-cycle current, the hardening depth amounts to about 60 to 70 mm. (2½ in.), while in the 500-cycle practice it amounts to approximately 40 mm. (1½ in.). It was concluded that 500 cycles for medium thickness plates (up to 100 or 120 mm. — 4½ in.) and 50 cycles for thick plates (200 to 400 mm. — 8 to 16 in.) gave the best results. The 50-cycle operation would give too deep a penetration for, say, an 80-mm. plate; if the travel is speeded, incorrect surface hardnesses result.

Mechanical properties were reported in terms of tensile strength, as noted above. Results obtained vary according to the analyses of the plates. With a base hardness of 105,000 to 120,000 psi. (and up to 155,000 psi. for tank construction) the resulting tensile figure of the hardened zone varies between 225,000 and 300,000 psi.

After hardening, plates were sometimes given a low tempering at about 400° F., presumably for some slight stress relief.

A wide range of analyses was investigated: Carbon 0.25 to 0.50%; silicon 0.3 to 0.5%; manganese 0.3 to 1.5%; chromium 1.0 to 3.0%; nickel 0 to 2.5%; molybdenum 0 to 0.4%.

Ballistic tests are reported as follows:

1. Marine armor plates, 2 to 6 in. thick, base tensile strength about 120,000 psi.: On attack with heavy calibers (that is, 150 to 300-mm. armor piercing shells, with striking velocity of about 1475 ft. per sec.) the plates reached the check production conditions for Krupp's carburized armor plate. The surface tensile strength had to amount to 270,000 psi. and more to get the required results.

2. Armor plates for casemate construction, 10-in. base, tensile strength about 120,000 psi.: On attack with 210-mm. armor piercing shells these plates showed up considerably better than the homogeneous armor plates ordinarily used. It was impossible to compare them with carburized plates, as these have not been used for casemate construction.

3. Armor plates for tank construction, 3 to 6 in. thick, base tensile strength about 150,000 psi.: Attack with 75 to 105-mm. armor piercing shell with velocities from 2000 to 2600 ft. per sec. demonstrated that plates of high base tensile strength were not noticeably improved by electric surface hardening against attack with medium calibers of high velocity. Further experiments with other analyses and tensiles might change this conclusion.

4. "Medium hard" armor plates for "man o' wars", 2½ to 4 in. thick: This is a weldable plate with low carbon content (below 0.3%) which, in contrast to carburized armor plate with higher carbon content, can be welded in the supporting structure of the ship, whereas the carburized type can only be fixed or bolted. Due to the low carbon content, these plates harden to a lesser degree. In compensation, the hardened zone is thicker than usual, being about half of the entire thickness. The tensile strength was about 225,000 psi. at the surface, and the base was 115,000. On attack with 150-mm. armor piercing shell an evident improvement over homogeneous plates of equal thickness was found.

Summary and Conclusions

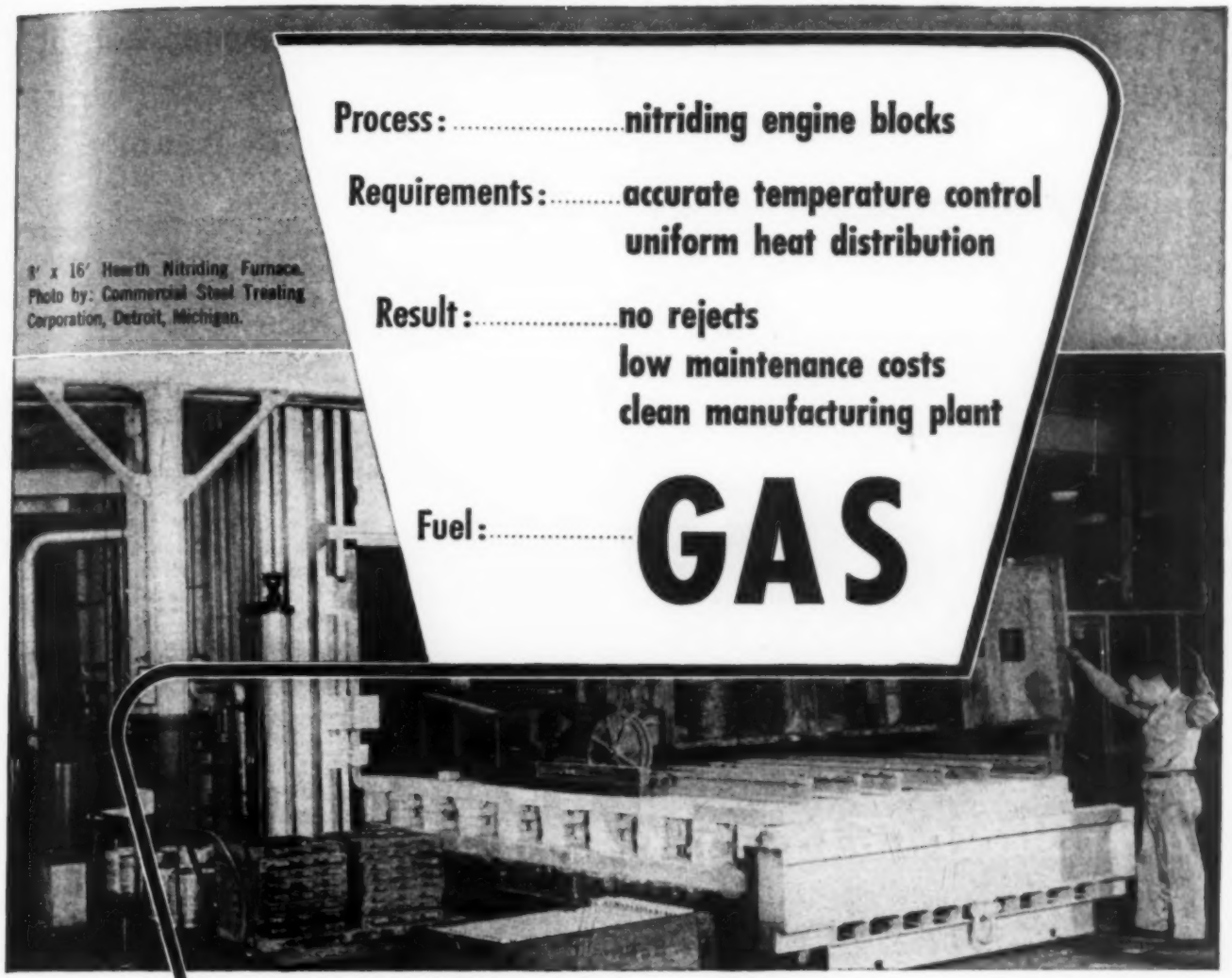
This visit to Dortmund-Hoerder Huttenverein, Hoerde, Ruhr, was made to investigate the capabilities of the equipment there for surface hardening of armor plates by electrical induction methods.

The equipment can harden plates up to 7 ft. wide, 24 ft. long and thickness of 16 in. (and possibly greater) at a rate of the order of 8 in. per min., giving a hardened layer up to 2¾ in. thick.

The equipment was built essentially for naval armor research and the bulk of the work has been conducted on thick naval armor. Experiments on tank armor have constituted a minor part of the research program, but results indicated that the process is most likely to show advantages in thick naval armor.

Good results were obtained for thin tank armor, of the order of 1-in. plate, giving ballistic results equal to, if not better than, carburized armor, and 30% better than homogenous plate against uncapped shot. This advantage was found to decrease, however, as the plates become thicker, until at 4 in. little improvement was obtained.

In answer to my question, "Is this process worth while for tank armor?" Dr. Wasmuht, the chief metallurgist, said he advocated *production* of naval armor and armor for land and coast fortifications by this method, and further *research* for tank armor. Insufficient alloys were available toward the latter end of the war in Europe for him to study tank armor. Further investigation would apparently be worth while, even though it is generally known that face hardened tank armor was abandoned by Germany in 1943.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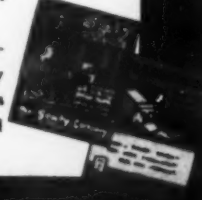

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An Experimental Gas Carburizing Program*

AS THE RESULT of a thorough research concerning gas mixtures and flows in connection with gas carburizing, the author points out the conditions under which commercial gas carburizing is best accomplished, largely by demonstrating the inadequacy of contaminated mixtures.

In general, the test data are derived from rather small specimens. Steel bars, approximately ⅜ in. diameter by 6 in. long, are inserted in silica tubes, ¾ in. diameter; these tubes serve as the reaction chamber. The apparatus and flows are thus of small-scale dimensions, and the research becomes one of laboratory conditions.

Flows are carefully controlled and are measured by orifice gages. The gases checked include "town gas", butane, propane, and combustion products re-formed over hot charcoal. In combination, diluting gases employed are air, partly burned city gas, and products of combustion passed through a bed of hot charcoal.

The temperature range for the carburizing experiments is from 1400 to 1750° F., while time at temperature ranges from 2½ to 10 hr. The prepared samples are thoroughly examined by four methods: change of weight, chemical analysis of turnings, photomicrographs and hardness gradients. The results are tabulated and shown by over 100 plots and pictures.

The author interpolates the report with qualitative deductions concerning the mechanism of adding carbon to steel surfaces. The report — both in the technique employed and the analysis of data — follows closely that of Bramley and coworkers and their work is quoted extensively

Raw city gas containing 2.6% CO_2 is found to be very erratic, and has a pronounced tendency to soot the work. Raw butane rapidly soots the reaction chamber, although the addition of combustion products affords an improvement. Propane with air is equally undesirable, but the use of combustion products with propane offers some improvement. The author *(Cont. on p. 962)*

★Abstracted from "Gas Carburizing", by Ivor Jenkins. Iron and Steel Institute Advance Copy, June 1946.

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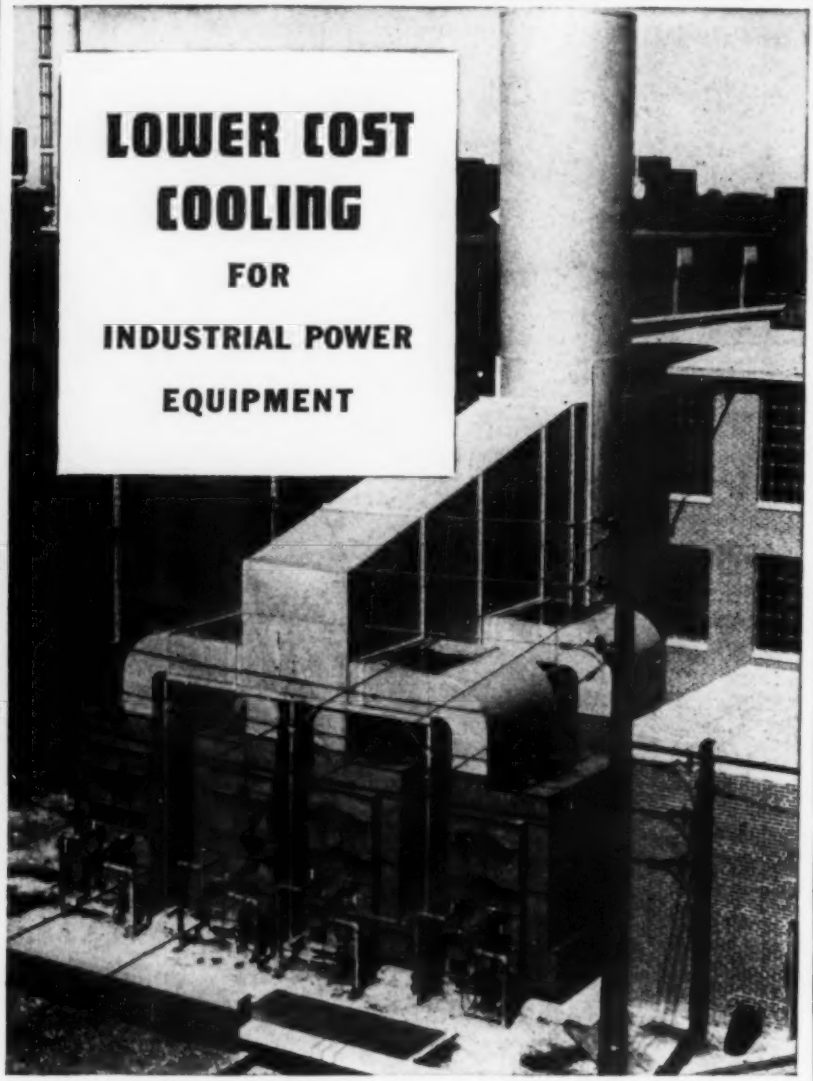

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Gas Carburizing Program

(From page 960) then demonstrates that products of combustion from which water vapor has been removed (leaving CO_2 and N_2) may be re-formed over hot charcoal (giving a final composition of 20% CO, less than 0.5% H_2, remainder N_2); this carrier gas with the addition of small amounts of propane gives a controllable mixture with little sooting and with a high carburizing value.

The author concludes the report with a consideration of carbon monoxide-hydrogen mixtures without propane, in an effort to control surface concentrations without diffusion periods. The effect of hydrogen is to increase the carbon availability of the mixture.

The austenite-ferrite interface where carburizing is accomplished below the upper critical point is discussed briefly from the temperature viewpoint. Also included is a demonstration of the effect of roughening the steel surface prior to carburizing.

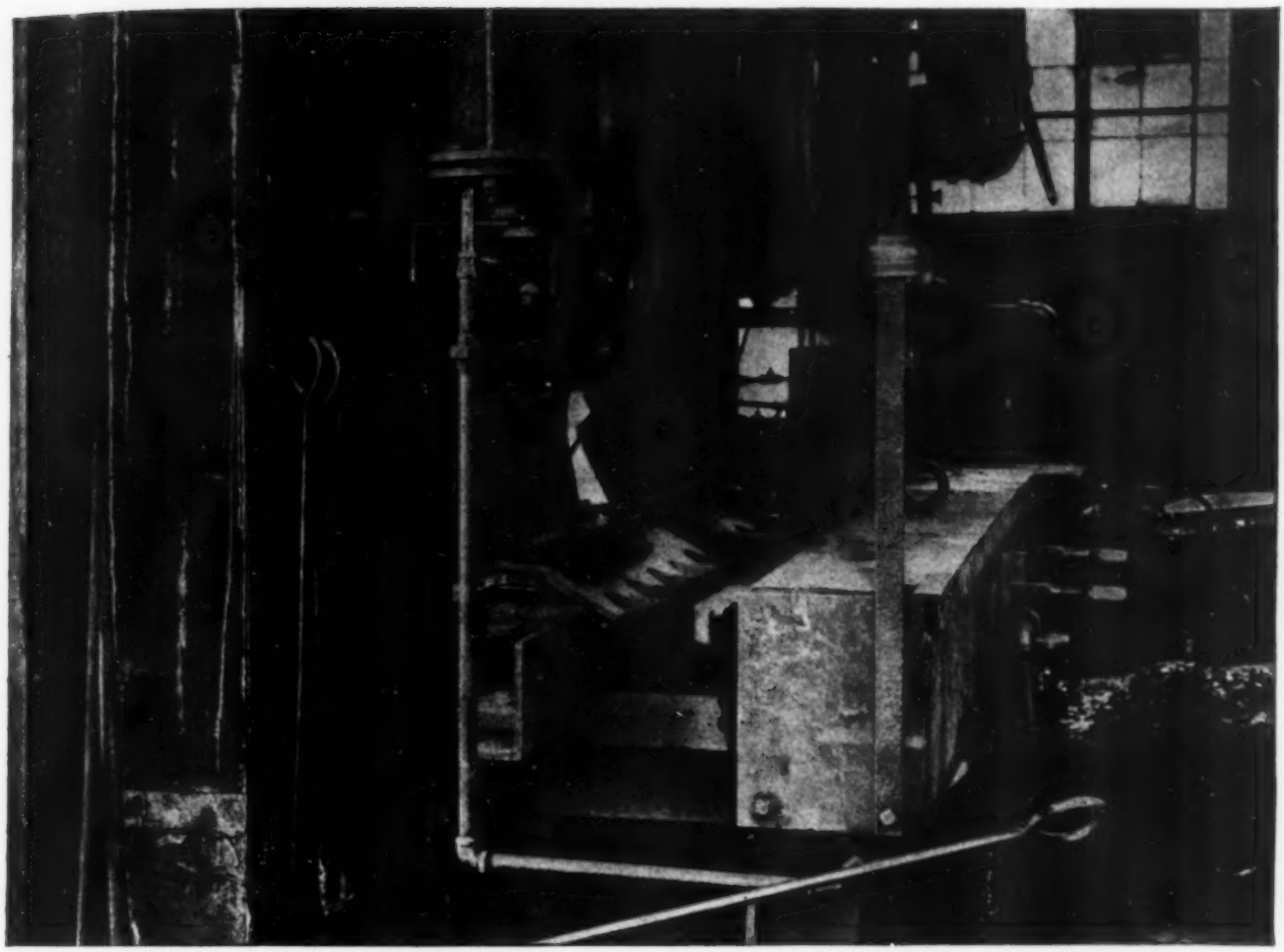
In this research the experimental conditions are controlled with care and completeness. Equally painstaking technique is evidenced in the measurement of the carbon added.

It is rather difficult to correlate the flow data cited with conditions prevailing under commercial carburizing. For example, an increase in flow rates is treated in the paper as evidencing the effect of velocity on carbon transfer rates. But an increase in gas velocity also means an increase of the volume furnished. This is an important point, when considering the matter of carbon availability.

The use of a large retort, with recirculation of the gaseous media, tends (in this commentator's opinion) to improve the test conditions. This is particularly true if the intent of the experiment is to obtain quantitative, rather than qualitative, data.

It would seem that the time is close at hand when dependable data for the diffusion rates of carbon both in austenite and ferrite should be available. From there, a simple use of the iron-carbon diagram would be effective in analyzing rates of carbon flow. Similarly, an analysis of carbon available from the gaseous media is equally

(Continued on page 964)



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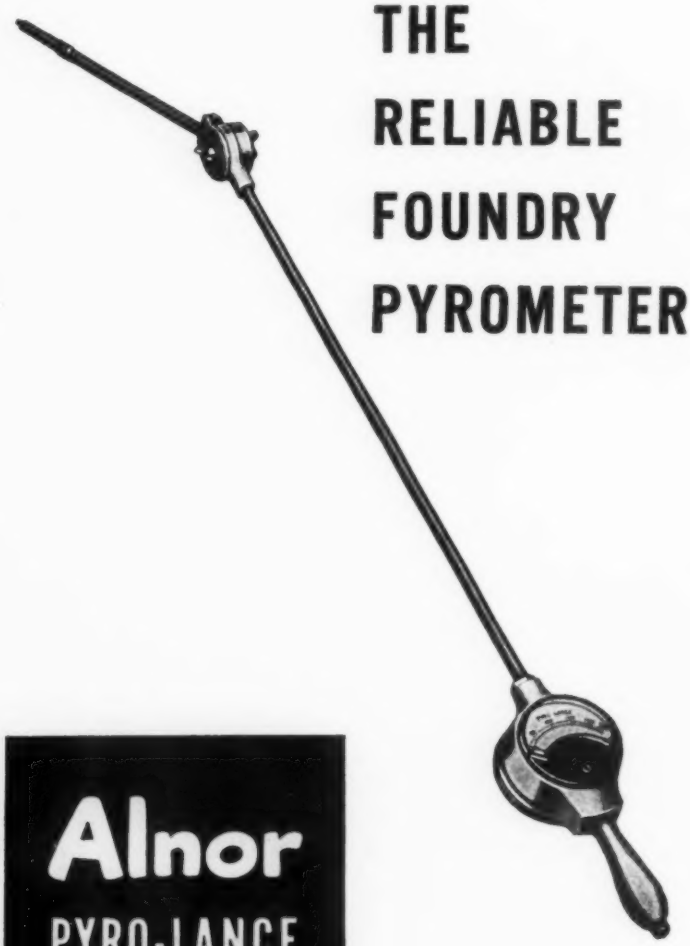

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Gas Carburizing Program

(Starts on page 960)

valuable in interpreting transfer conditions. Until these factors are established in quantitative fashion, it is difficult to define accurately the conditions demanded for controlled gas carburizing.

F. E. HARRIS

Quench Cracking*

IT IS GENERALLY recognized that the greatest toughness at any given strength is found in steels having a tempered martensitic structure. For any given part, it is necessary to use a steel with sufficient hardenability to avoid the pearlite and the bainite reactions. However, this requirement does not fix the combination of alloying elements to be used; an infinite number of steels would have the required hardenabilities. Frequently, it is very desirable to minimize the tendency toward quench cracking while maintaining the necessary hardenability. Since a low M_s (martensite start) temperature increases the tendency toward quench cracking, the problem becomes more specific. It is necessary simply to design the steel to have the required hardenability with the maximum M_s temperature.

To attain this goal, namely full hardening with a minimum susceptibility to quench cracking and to the retention of austenite, the composition should be such that further slight additions of each element give as great a fractional increase of hardenability per degree lowering of the martensite temperature range as possible. On the basis of the data now available, this means that the following considerations should be taken into account for hypo-eutectoid steels.

The carbon content should be as low as possible to permit the maximum toughness of the tempered steel as well as the maximum M_s temperature. Silicon should be as high as is consistent with good steel quality and toughness, since it does not affect the M_s temperature yet increases the bainitic hardenability. *(Continued on page 966)*

*Abstracted from "Hardenability and Quench Cracking", by L. D. Jaffe and J. H. Hollomon, *Metals Technology*, January 1946 (A.I.M.E. Tech. Pub. No. 1927), 8 p.

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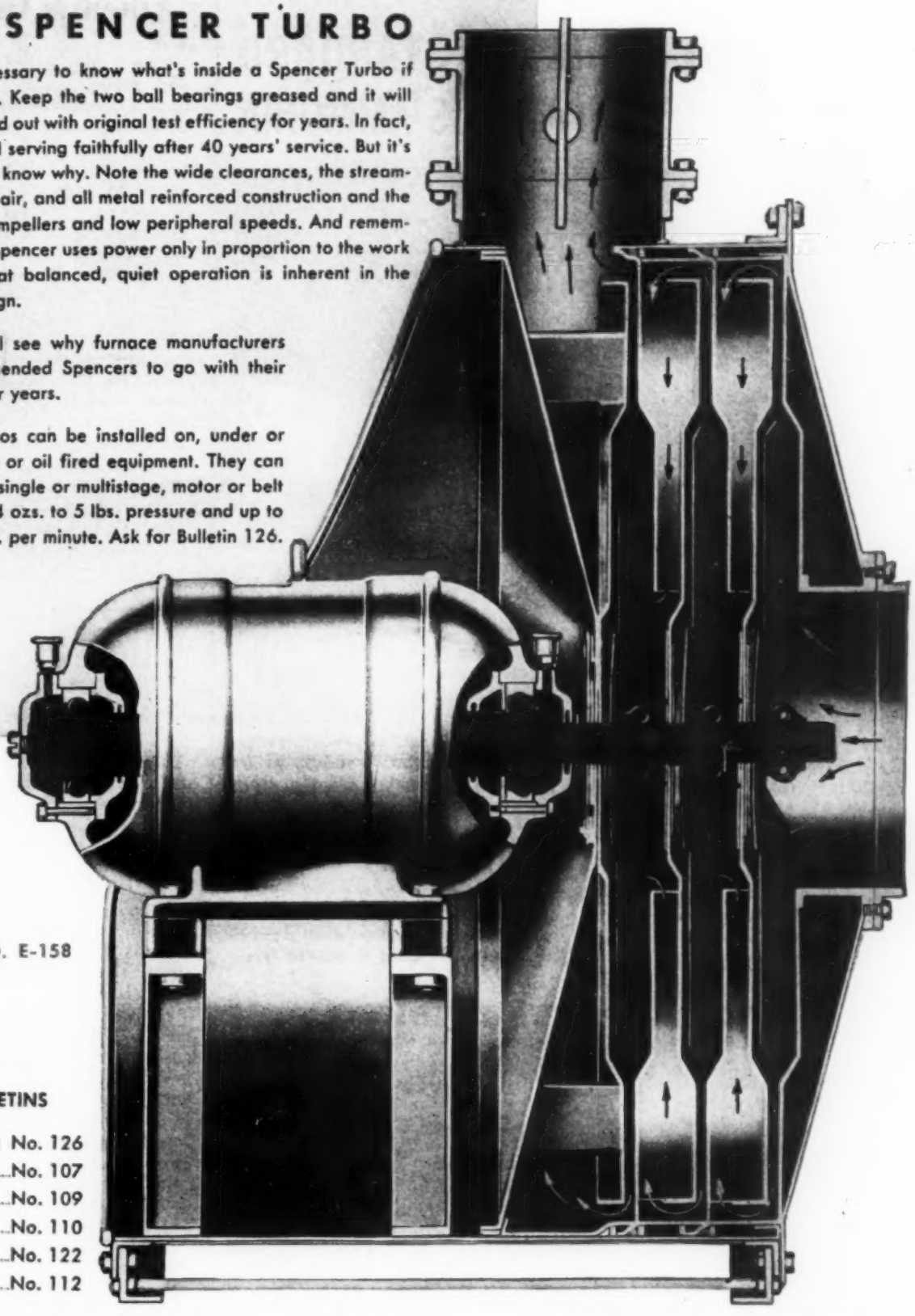

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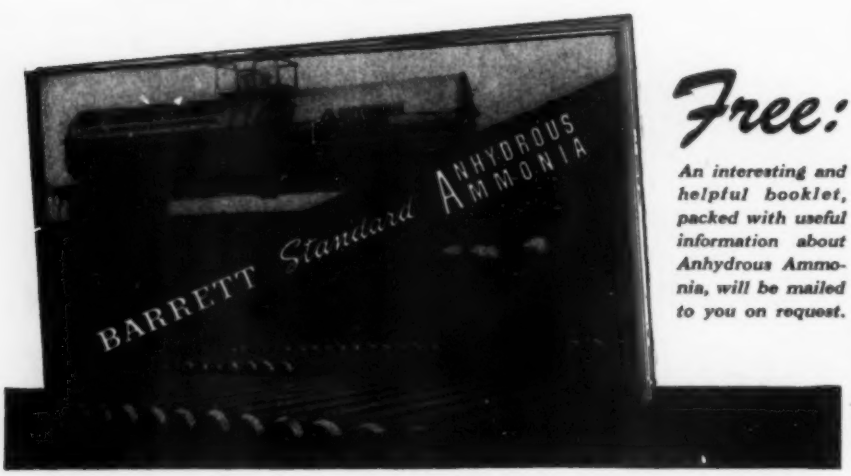

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Quench Cracking

(From p. 964) Manganese, chromium and nickel concentrations should bear a definite relationship to each other and should be as high as is necessary to give the required bainitic hardenability. A curve is given to indicate the optimum proportions for each based upon maximum bainitic hardenability with minimum lowering of the M_s temperature. Once the required bainitic hardenability has been obtained, enough molybdenum should be added to give the required pearlitic hardenability.

Besides hardenability and tendency toward quench cracking and austenite retention, other considerations may influence the choice of alloying elements. However, the composition of the steel should be adjusted as suggested if the required hardenability is to be obtained with a minimum tendency toward quench cracking.

Nature of Tempered Martensite*

IT IS GENERALLY accepted by metallographers who have studied the crystallography of martensite that martensite in eutectoid steel consists of carbon atoms in the middle of the edges of interpenetrating unit cells of α iron—12 such cells (24 iron atoms) distorted by one carbon atom. This results in the tetragonally distorted unit cell, a solid solution of carbon in α iron.

No such agreement exists as to the structure after the first stages of tempering, and the present research studied, by X-ray diffraction methods, the structure of 0.89% and 1.26% plain carbon steels after quenching and tempering at 212° F. The X-ray films showed diffuse ferrite lines, which may be explained as follows:

In martensite formed in a steel of eutectoid composition (pearlite), one carbon atom distorts a set of 12 iron unit cells. Raising the temperature to, say, 100° C., at which temperature such martensite can be tempered, enables the artificially retained carbon atoms to escape from their unnatural *(To p. 978)*

★Abstracted from "The Structure of Tempered Martensite", by W. J. Wrazej. Iron and Steel Institute Advance Copy, July 1946.

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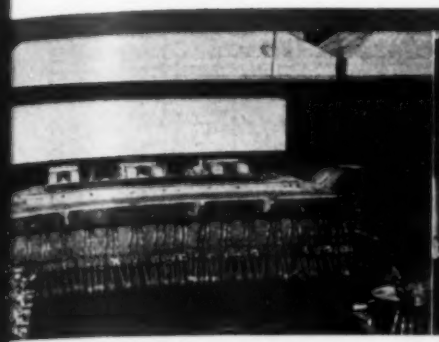

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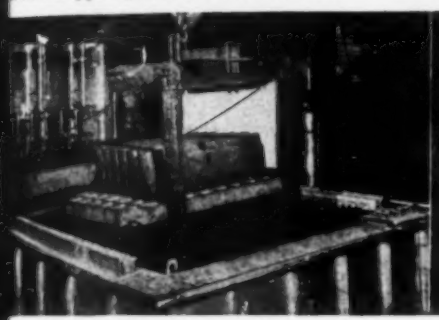
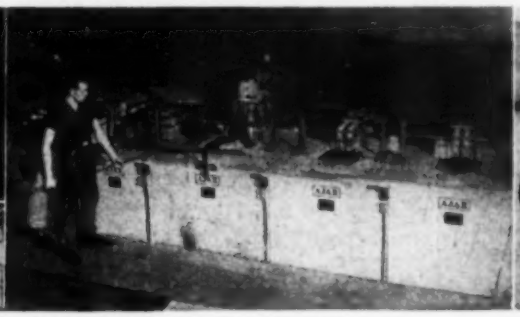
NEUTRAL HARDENING carbon and alloy steel parts without scale or decarb.



LIC ANNEALING 9-ton charge of crusher plates in Ajax salt bath quench furnace.



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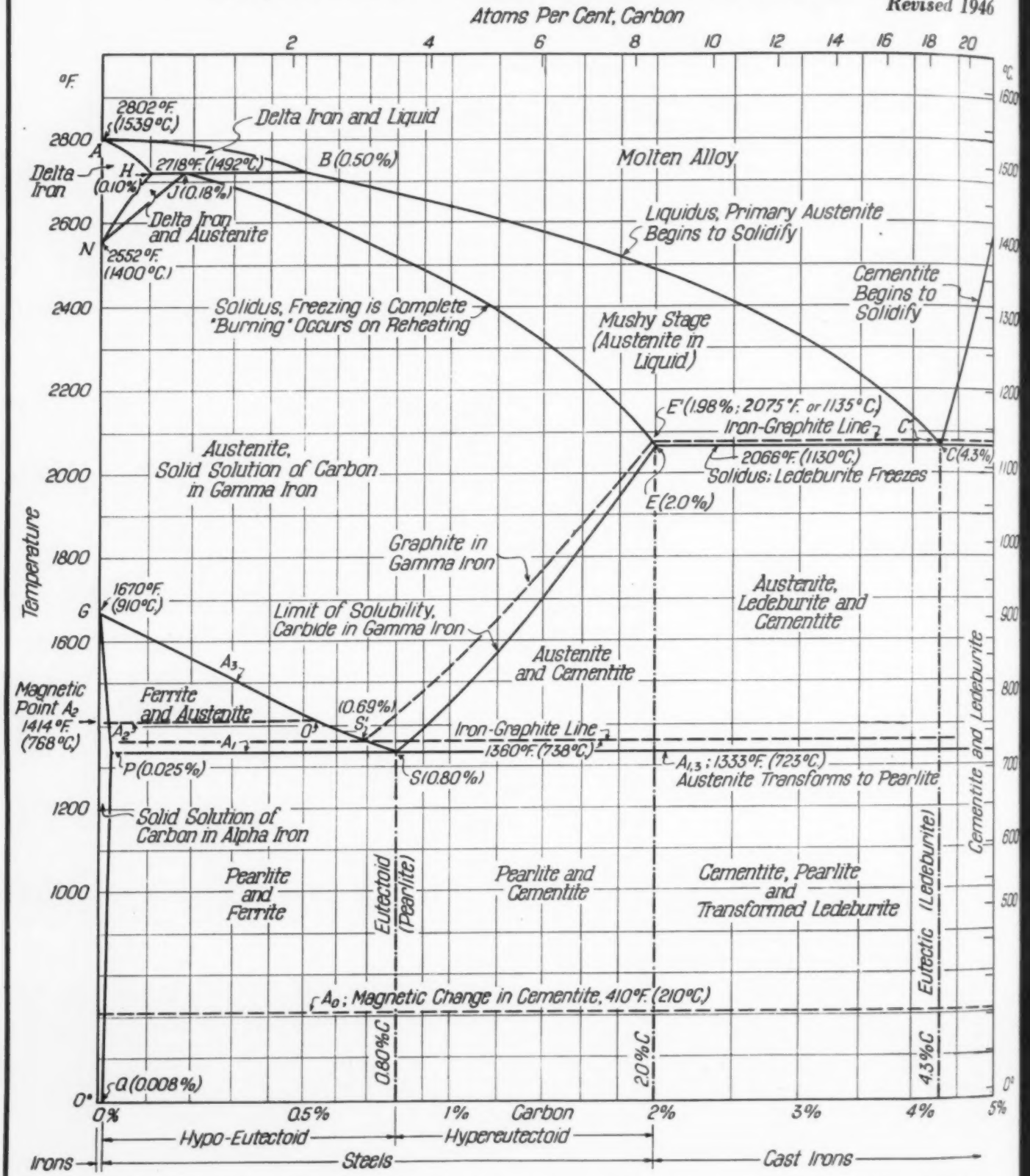
AJAX HULTGREN ELECTRIC SALT BATH FURNACES

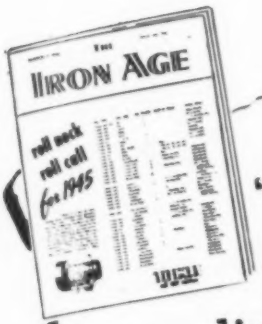
Iron-Carbon Equilibrium Diagram

Revised 1946



Principal points and lines, especially *G-S-E-J*, adjusted from positions in former edition of *Metal Progress* data sheet, to agree with diagram prepared for the subcommittee on phase diagrams, Kent R. Van Horn, chairman, John S. Marsh and F. N. Rhines, for inclusion in the 1947 Metals Handbook. Point *Q* according to J. H. Whiteley, *Journal* of the Iron and Steel Institute, 1936.

HOW TO STOP WASTING STAINLESS STEEL...



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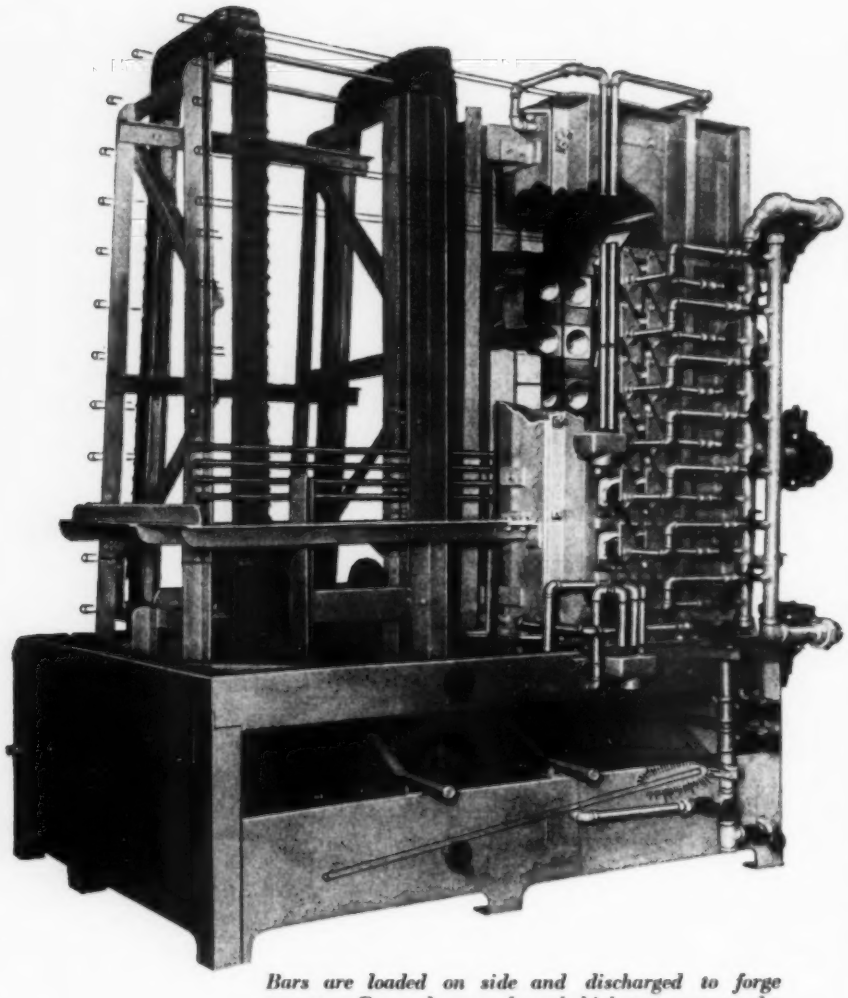

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Martensite

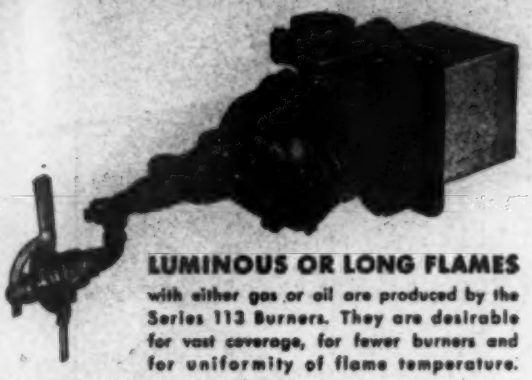
(Cont. from p. 966) positions in the α iron unit cells. It is known that carbon forms cementite of orthorhombic structure, and that the unit cell of cementite contains four carbon and 12 iron atoms ($4Fe_3C$). To form such a unit cell of cementite, neighboring sets of α iron unit cells (martensite) must give off their carbon atoms. Since an elementary grain of cementite is built up of multiples of $4Fe_3C$, the ferrite block which supplied the carbon must be assumed to be composed of the same multiples of α iron sets. It may be assumed that particular blocks will be of different size throughout the tempered martensite grain.

The cementite may be visualized as layers or plates deposited to a thickness of some multiple of a unit cell along one of the principal planes. Such plates, composed of orthorhombic unit cells with parameters different from that of the adjacent unit cells of ferrite, will distort the latter. An expansion of the parameter of ferrite produced in this way is not an indication that it contains carbon in solution. It is easy to visualize the thickening of the cementite plates and of the ferrite blocks in the course of further tempering, which will eventually convert the cementite into small globular grains. This granular cementite will cause less distortion of the adjacent ferrite than the primary plates, so that the parameter of the ferrite must be reduced.

Each grain of tempered martensite must be assumed to be a mixture of minute blocks of ferrite and cementite or to consist of ferrite with cementite precipitated in primary shape and size. Owing to the differences in the structure of the two phases (cubic ferrite, orthorhombic cementite) and in the parameters, there will be stresses in the grain. The small particle size of the ferrite as well as the internal stresses due to the distortion of its lattice will cause the broadening of the lines in the X-ray film.

Therefore, this first stage of tempered martensite is not a new variety of martensite (sometimes called β martensite), as this would be a cubic lattice containing carbon atoms or cementite (Fe_3C) in solid solution. Rather it is ferrite (α iron, freed from carbon atoms) mixed with precipitated cementite in layers or plates.

Pioneered by **North American**



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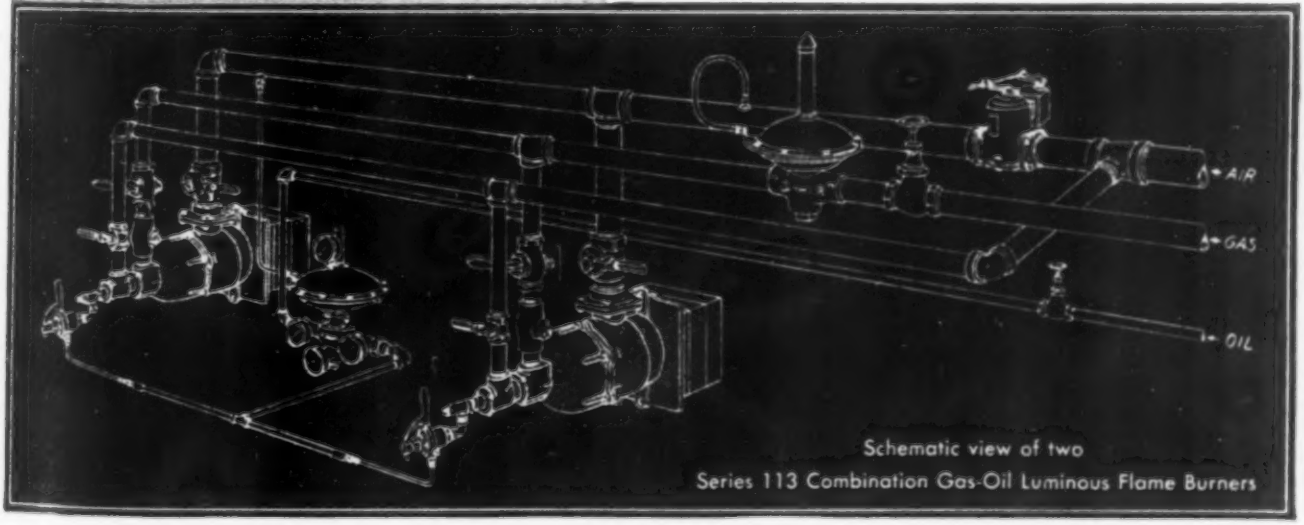
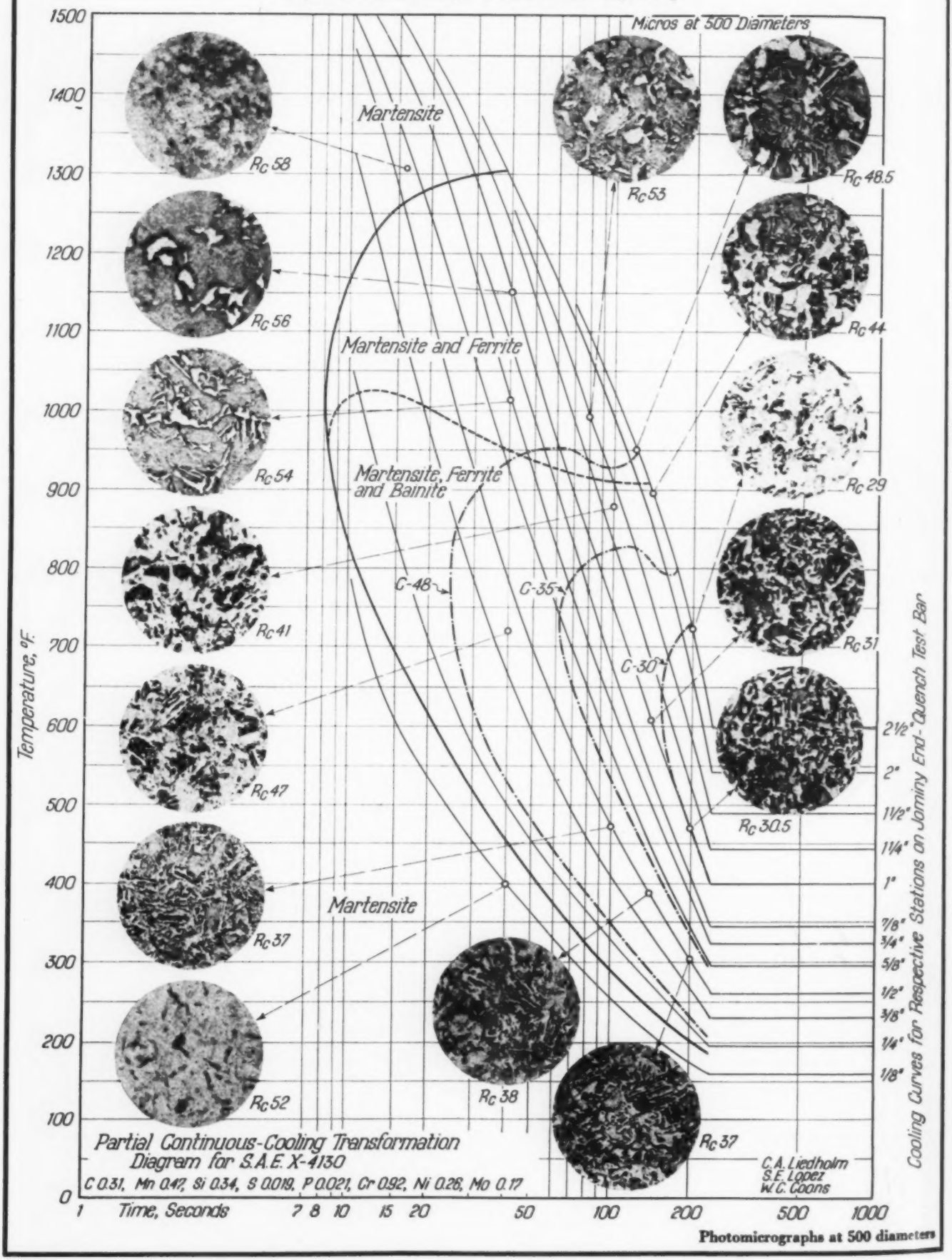


Schematic view of two
Series 113 Combination Gas-Oil Luminous Flame Burners

Transformation of X-4130 Steel

During Continuous Cooling

By C. A. Liedholm and Associates, Curtiss-Wright Corp.



Photomicrographs at 500 diameters

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Standard Hardenability Test

THE APPROVED METHOD of measuring hardenability is known as the Jominy End-Quench Test and consists of cooling the end of a 1-in. round bar with water and measuring the surface hardness at regular distances from the water cooled end. This method was first described by A. L. BOEGEHOLD and W. E. JOMINY in 1937; standardized routine of the test was agreed upon by "The Steel Standardization Group" in 1941 and is described at length in the 1945 S.A.E. Handbook, page 312. (Note 1.)

The approved bar is shown below, and has a collar machined on the end to suspend it in a simple fixture. (Note 2. Collar may be a washer spot welded to the end of a 1-in. bar; optional specimen with tong hold is shown at lower right.)

The test bars should be normalized by heating to 150° F. above the Ac_3 point and holding 30 min. at heat. Following this treatment the bar is finish machined (Note 3) and heated for hardening to 75° F. above the Ac_3 point, holding 20 min. at heat. If controlled atmosphere furnace is not available, to minimize scaling the bar should be heated in a small closed container having a layer of cast iron chips about 1 in. deep (or stood on end in a loosely fitting stainless steel cup).

The quenching holder is mounted so that a column of water at 75° F. ± 5° is directed against the bottom face of the hot test piece. The water passes through an opening ½ in. diameter and is under sufficient pressure to rise to a free height of 2½ in.

In performing this test the water supply is shut off with a quick-opening valve, the hot specimen placed in the fixture so its bottom is ½ in. from the pipe opening, and the water quickly turned on. The sample is kept on the fixture until cold (or for at least 10 min., and then quenched in water until cold).

Two flats are then ground 0.015 in. deep, 180° apart, along the sides of the round bar, taking pains to avoid heating and drawing the hardness of the piece. (Note 4.) Rockwell hardness readings are then made over the length at 1/16-in. intervals.

Notes Added by W. E. Jominy, May 1946

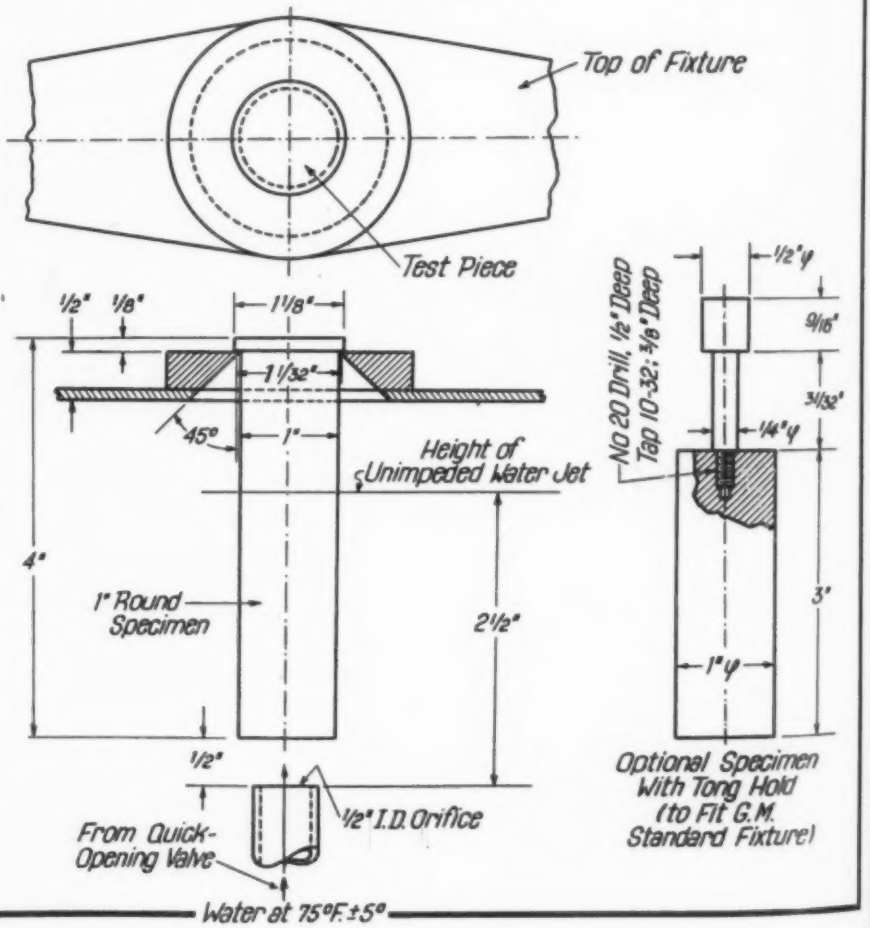
1. Inasmuch as carbon, manganese and other elements tend to segregate during solidification of the ingot, hardenability test bars machined from billets near the top of the ingot will usually have higher hardenability than those machined from near the bottom of the ingot. The following table, in rather common use, gives the limiting hardness with carbon content and may be used as a guide in applying hardenability specifications for alloy steels:

0.08 to 0.17% C	C-25
0.18 to 0.22	30
0.23 to 0.27	35
0.28 to 0.32	40
0.33 to 0.38	45
0.39 to 0.48	50
0.48 to 0.53	55

2. If the hardenability test bar is to be made from larger than a 2-in. round specimen, it may either be forged to a 1¼-in. round or the specimen can be machined from a position half way from center to surface of the piece. If the bar is forged it will usually show higher hardenability than if machined from the larger piece.

3. The normalized bar should be large enough in diameter so that all of the decarburized layer is machined off in finishing to 1-in. round, prior to hardening.

4. It is good practice to etch the ground flats to determine whether any burning has resulted from the grinding.



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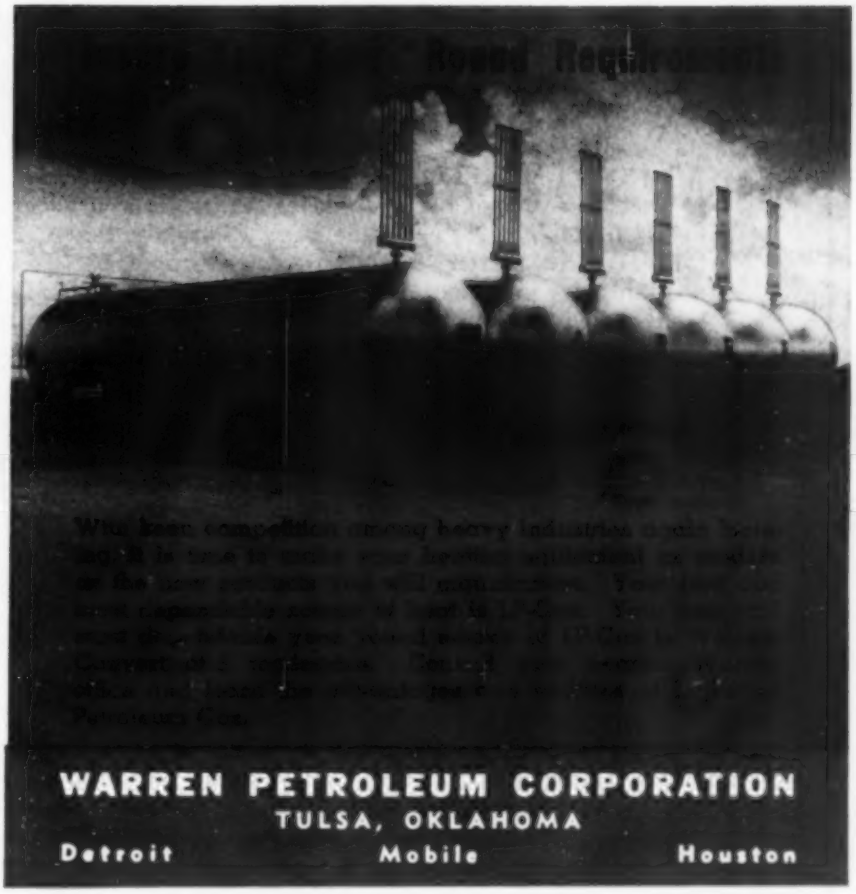

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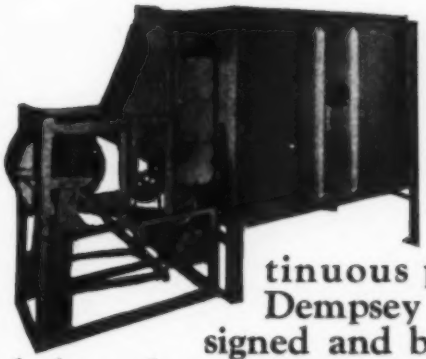

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Precautions in Handling Cyanide

With Notes on First Aid

Data Sheet by E. F. Houghton & Co.

MANY COMMERCIAL PREPARATIONS for use in the heat treatment of steel contain poisonous cyanide as an essential if not the principal ingredient. Their use is perfectly safe if simple precautions are taken, and has been so widespread that all heat treaters with any considerable background of experience are well acquainted with them, and recognize the hazards and how to avoid them. Newcomers in industry, however, must be properly and promptly instructed, in no uncertain terms; such instructions should be repeated until the supervisor is certain the workmen understand the dangers and how to avoid them.

Rules for Handling Salts

1. Use scoop and dry cotton gloves.
2. Do not handle cyanide if you have any broken skin or open wounds on hands or wrists.
3. Wash hands thoroughly after handling.
4. Keep the container covered when in storage.
5. Open the container only in the room or building in which the cyanide compound is used.
6. Keep cyanide salts away from acid. Cyanide in the presence of even the weakest acid will liberate the deadly gas known as hydrocyanic acid.
7. Food should not be stored, handled or eaten in the vicinity of cyanide mixtures.
8. Wear rubber gloves when operating the bath or handling articles which have passed through it.
9. In case any irritation of the skin develops as a result of handling cyanide, consult a physician immediately.
10. Burns from molten cyanide salt mixtures are treated as any burns caused by alkalies. Wash the area thoroughly with warm water to remove chemicals; then treat as any burn. If the burn is at all severe, see the doctor immediately.

Operating the Salt Bath

While not to be considered as a complete manual, observance of the seven suggestions below will avoid the common dangers to personnel operating salt baths.

1. Do not mix a compound containing cyanide with one containing nitrates or nitrites, or put one in a container which has been used for the other. Violent reaction and possible explosions result from such mixtures. Material treated in a bath of one sort should not be processed in a bath of the other until it has been thoroughly cleaned. Containers of the original salts are properly labeled so such mixing can be avoided. In case of doubt, don't mix.

2. Keep asbestos gloves always at hand.
3. Wear safety goggles or face mask when operating the bath.
4. Hoods and stacks are advisable for salt baths.
5. All work must be thoroughly dry before introduction, or splattering may result.
6. When bailing out a bath, molten salt should not be stored in a mold or container deeper than 6 in. The risk of serious eruption while solidifying increases with depth.
7. To avoid remelting hazards in all furnaces except those which heat from the top down (as the internal electrode type) follow this procedure: Before the bath freezes, insert a cast iron wedge with tip touching the bottom while the thick end projects at least 4 in. above the surface. The vent remaining when the wedge is removed from the solidified salt will permit the escape of gases on remelting. Remove the wedge by tapping with a hammer, but not until the bath is completely solidified — if removed earlier, molten salt below the surface may erupt.

First Aid for Cyanide Poisoning

First aid is the emergency treatment to prevent further harm or possible death. It is applied immediately, prior to the arrival of physician.

The first requirement is to obtain from a druggist and always have on hand for instant use in the first aid cabinet *in the heat treat:*

Amyl nitrite pearls (heart stimulant).

Sodium thiosulphate, 1% solution (an emetic, to induce vomiting and empty the stomach).

Call physician immediately; meanwhile apply first aid treatment promptly as follows:

If patient is conscious and breathing

1. Break an amyl nitrite pearl in a piece of cotton gauze and hold lightly over his nose while the patient inhales.
2. If cyanide has been swallowed, induce vomiting by giving a pint of sodium thiosulphate, 1% solution. If this is not ready at hand (which is inexcusable) give copious drinks of soapy water, mustard water, or bicarbonate of soda (2 teaspoons to pint of water). Continue the use of any of these emetics until the patient throws up a clear solution, which proves his stomach is empty.

If patient is unconscious but breathing

1. Break an amyl nitrite pearl in a piece of cotton gauze and hold lightly over his nose while the patient inhales.
2. Follow with oxygen from an inhalator, if it is available.
3. Give nothing by mouth to an *unconscious* man.

If patient is not breathing

1. Give artificial respiration at once, continuing until physician arrives.
2. While artificial respiration proceeds, an assistant breaks an amyl nitrite pearl in a piece of cotton gauze and holds it to the patient's nose.
3. Give nothing by mouth to an *unconscious* patient.

284 GROVE STREET
WORCESTER 4-1795

By M. Eugene Merchant
Research Physicist
The Cincinnati Milling Machine Co.
Cincinnati, Ohio

Machinability Versus Physical Properties —an Example

THE METALLURGIST knows well that the microstructure of a metal strongly influences its machining properties. He does not have to be told that machinability varies with grain size. He knows that the presence of very hard or abrasive constituents in the structure may greatly increase tool wear. All this and more is right down his alley.

But what about "physicals"? How do these affect the ease of cutting when the metallurgy is constant? Or do they? What physical properties are important? How do these make themselves felt in the machining process? Here are troublesome questions, and here is where some new testing methods and techniques may come to the aid of the metallurgist.

To illustrate these, and to show how they might be used, let us follow the solution of a characteristic problem. This is it: Suppose that the shop foreman confronts the metallurgist with two samples of steel which machine very differently. Steel A behaves very poorly while steel B cuts very nicely — yet both are supposed to be of the same chemical composition. An analysis proves that this is true. (The data used in this problem, although discussed in general terms, have been taken from actual test results.)

As the first step, of course, the metallurgist studies the microstructure. But no difference between the two steels is found — no significant difference in grain size or in the nature and distribution of the microconstituents — and no abrasive inclusions appear in either. The conclusion is that the difference must lie in the "physicals"!

But here another surprise awaits. Hardness measurements show that steel A has a Brinell number of 160 and steel B, 140. The poorer machining steel has the greater hardness! Evidently the hardness is no reliable index of machinability (in this present instance). The metallurgist may then measure another important physical property, namely, the work hardenability of the materials, as measured by the so-called Meyer exponent, n. It is known that this property can affect the machining qualities of steels. But a check on the Meyer exponents of these steels gives n — 2.37 for steel A, and n — 2.39 for steel B. This is a negligible difference, and means that both steels will harden almost equally when plastically deformed to an equal degree. Clearly, the source of trouble is not to be found here.

How can such a situation exist? The answer is this: No measurement has been made of those

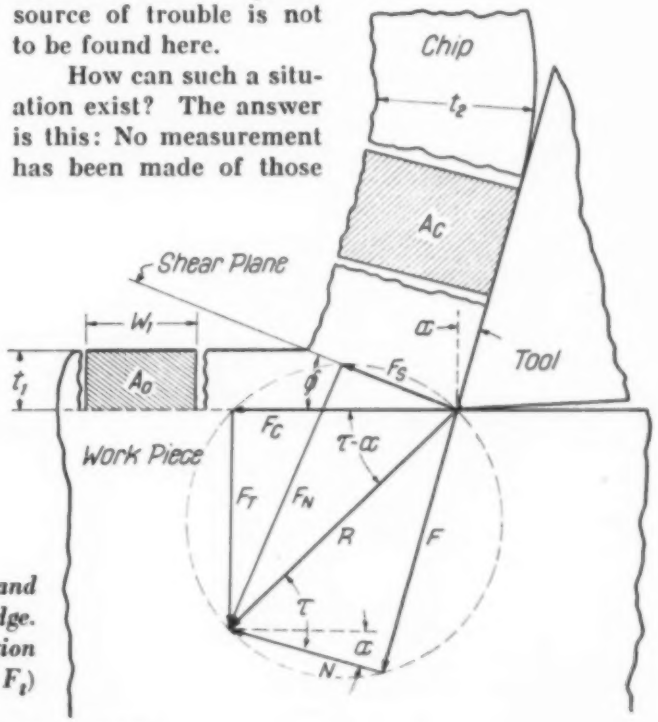


Fig. 1 — Schematic Representation of Chip Geometry and Force System for a Continuous Chip Without Built-Up Edge. (Single straight cutting edge at right angles to direction of tool travel; dynamometer readings give values for F_c and F_t)

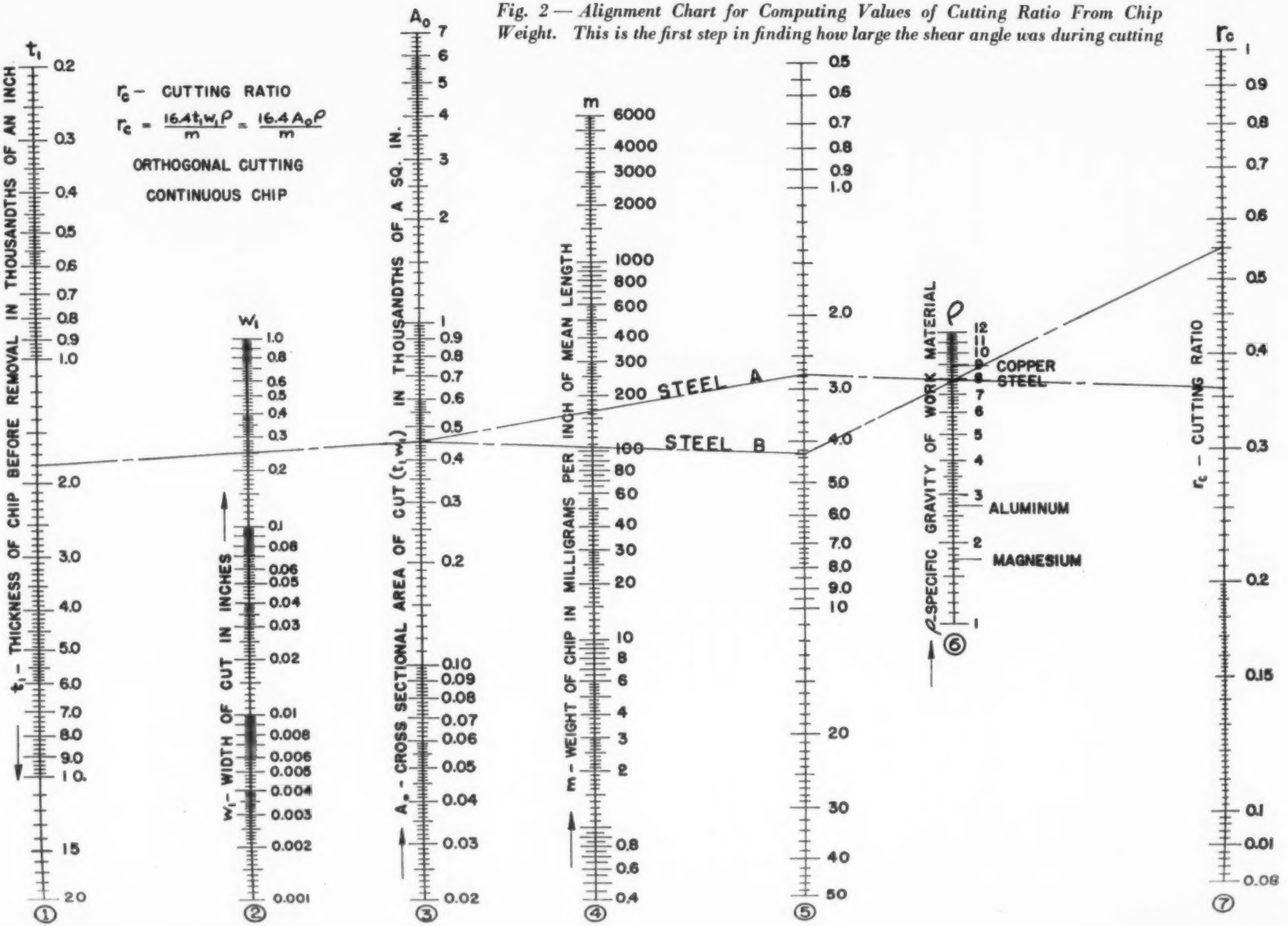
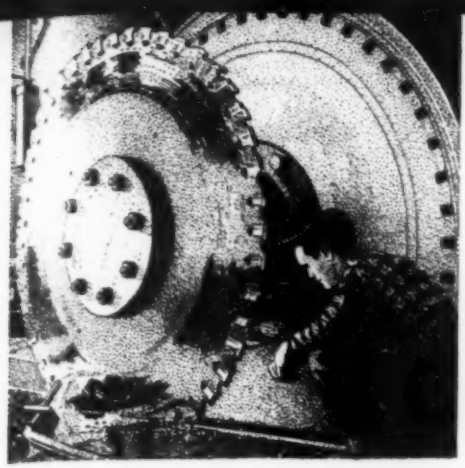


Fig. 2 — Alignment Chart for Computing Values of Cutting Ratio From Chip Weight. This is the first step in finding how large the shear angle was during cutting



physical properties which actually influence the cutting action — which really control chip formation and the forces on the cutting tool. These are the properties that must be measured. Of course, no one yet knows what all of these factors are. But recent theory and experiment have shown* that at least three properties of a metal play a very real part in determining its behavior when machined. These are:

1. The shear strength which the metal exhibits when being cut, which we will designate by the symbol S_s.
2. The coefficient of friction, μ, between the flowing chip and the face of the cutting tool, as measured by the friction angle τ. (See Fig. 1, page 1013.)
3. The rate of change of the shear strength of the material with applied compressive stress, as measured by an angle called C. This angle is the complement of the slope angle of the curve drawn when shear strength of the given metal is plotted against compressive stress. It is a property of the material.

The relationship of these three basic quantities to the cutting process is simplest when the conditions of chip formation are similar to those pictured schematically in Fig. 1. It is beyond the scope of this article to derive or to present in detail the relations between the above three properties and the process of cutting. A study of Fig. 1, however, will help to indicate how the three quantities are able to control forces and chip formation.

*"Mechanics of the Metal Cutting Process — II. Plasticity Conditions in Orthogonal Cutting", by M. E. Merchant, *Journal of Applied Physics*, V. 16, June 1945, p. 318 to 324.

In this simple example, chip formation takes place wholly by plastic deformation of the metal — the tool shears the metal (without fracture) on a plane extending from the cutting edge to the surface. This "shear plane" is shown in Fig. 1; it makes an angle ϕ with the line of motion of the tool. This angle ϕ, the shear angle, is a quantity which can vary; in so doing it will change the length of the path of shear.

The reader will see, after a little thought, that the resistance which the metal offers to shear will therefore depend on two factors — the shear angle ϕ (which determines the length of the path of shear), and the shear strength S_s of the metal. The shear strength of the metal is the first of the three basic properties listed above; its role in the cutting process should now be clear.

What of the other two properties?

It has been found that these two basic quantities, τ and C, control the value of the shear angle ϕ. The relationship is quite simple:

$$2\phi = C - \tau + \alpha \qquad (1)$$

(Here α is the true rake angle of the tool, as shown in Fig. 1.)

Now it is clear how the three physical properties S_s, τ and C, together with the rake angle α, can control forces and chip formation in cutting. The values of τ and C fix the length of the path of shear caused by the tool, while the shear

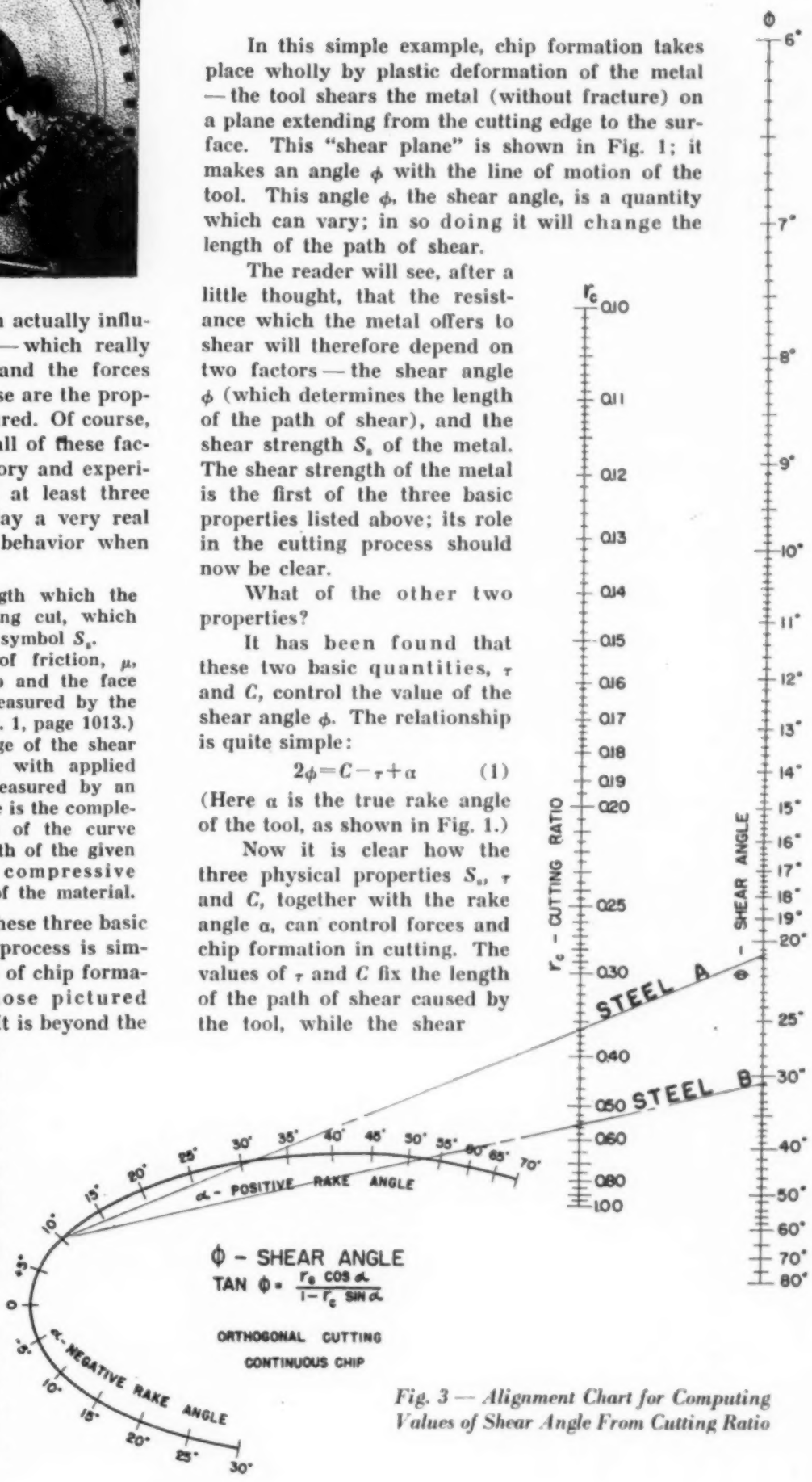

r_c - CUTTING RATIO
SHEAR ANGLE - Φ
STEEL A
STEEL B
α - POSITIVE RAKE ANGLE
α - NEGATIVE RAKE ANGLE
Φ - SHEAR ANGLE
TAN Φ = r_c COS α / 1 − r_c SIN α
ORTHOGONAL CUTTING
CONTINUOUS CHIP

Fig. 3 — Alignment Chart for Computing Values of Shear Angle From Cutting Ratio

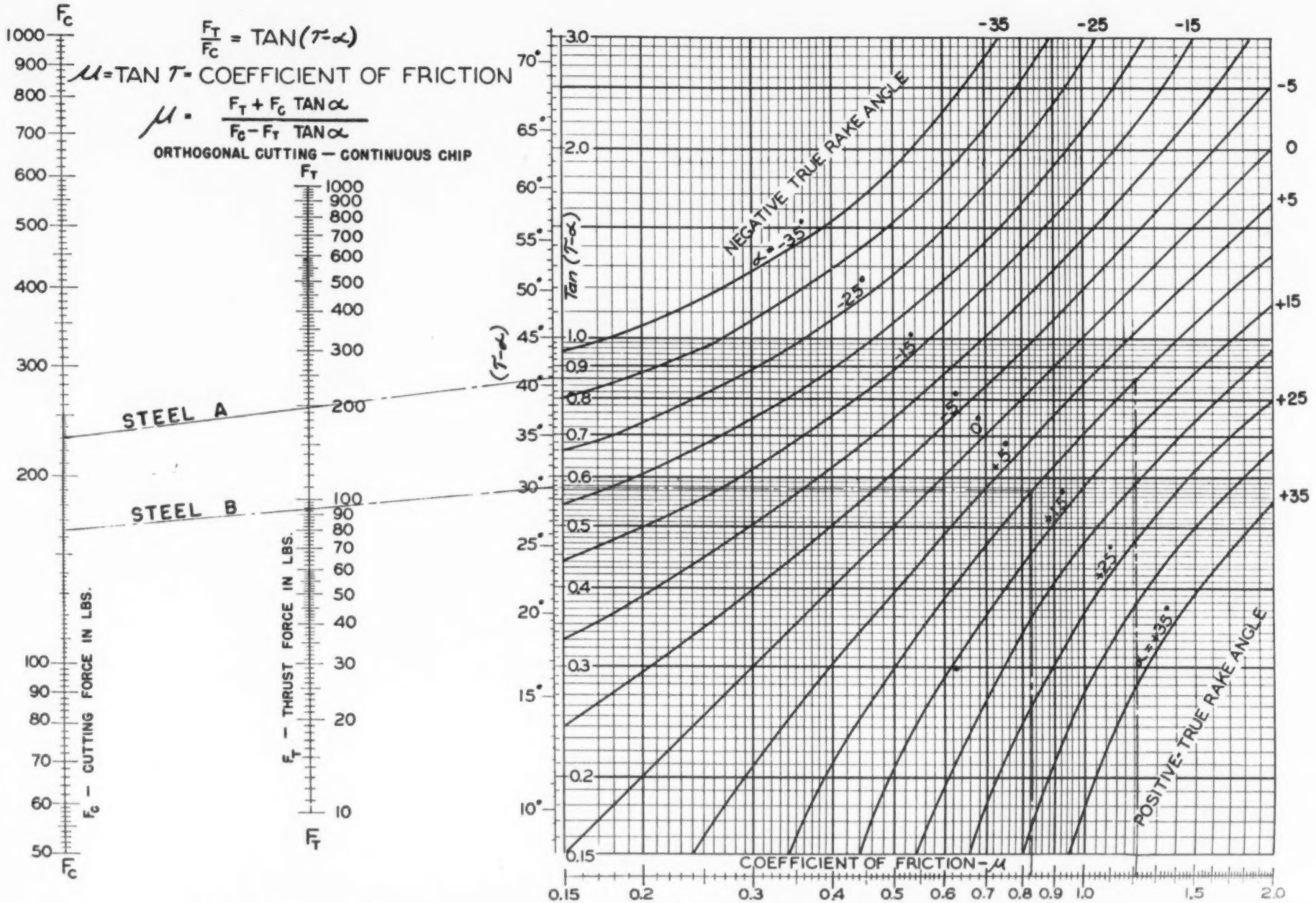


Fig. 4 — Alignment Chart for Computing Friction Angle and Coefficient of Friction From Observed Force Components

strength of the metal determines the basic resistance to shear along that path. When the metallurgist understands this, he has gone a long way toward understanding why steel A and steel B, with their similar metallurgy as described at the outset, can still machine so differently.

But for the metallurgist really to understand the differences between these two steels, he needs to express them in *numbers;* he needs to know the *values* of the three basic properties for both. Obviously, the best place to get the values that are acting during cutting is from cutting tests themselves — and this can be done. Equations have been worked out* by which one can calculate S_s, τ, and C from measurements taken in a simple test setup. These equations can be very readily applied when the chip formation is of the simple type already talked about.

It is beyond the scope of this article to go into all the details of the test methods that may be used; these have been fully described elsewhere.† However, three quantities must be measured — the two force components F_c and F_t of Fig. 1, and the mean weight per unit length of the continuous ribbon of chip obtained from the cut.

To simplify the computation of data from these measurements, alignment charts have been constructed, and can be used to solve the equations mentioned above. With these charts the three basic quantities can easily be obtained from the data gathered from the cutting test. These alignment charts are shown in Fig. 2, 3, 4 and 6. Their application to our problem of the two different steels is shown by appropriate guide lines, whose location will be discussed a little later, but first the metallurgist must know how to get the three experimental values required. He must make cutting tests on steels A and B; these must be of such a type as to give the simple kind of chip geometry that we have talked about here — a continuous chip without built-up edge made by a tool having a single straight cutting edge set at right angles to the line of motion. To get such conditions, our metallurgist friend may make use of a sintered carbide tool and a workpiece in the form of a tube (hollow round). The carbide tool gives, with steel, a continuous chip with little or no built-up edge. The tubular workpiece is used in the manner shown in Fig. 5; this gives the needed relation between tool and work.

*"Mechanics of the Metal Cutting Process — I. Orthogonal Cutting and a Type 2 Chip", by M. E. Merchant, *Journal of Applied Physics*, V. 16, May 1945, p. 267 to 275.

†"New Methods of Analysis of Machining Processes", by M. E. Merchant and N. Zlatin, *Proceedings* of the Society for Experimental Stress Analysis, V. 3, No. 2, 1946, p. 4 to 27.

To determine the values of the force components F_c and F_t for steels A and B, any reliable tool dynamometer may be used. Figure 7 shows a suitable mechanical type of tool dynamometer in action; the setup is similar to that described above. Let us suppose that our metallurgist is fortunate enough to have at hand a good dynamometer. Being a practical fellow, he has doubtless been busy setting it up and having samples of steels A and B made into tubes while the foregoing dissertation on theory has been going on.

He now selects cutting conditions suited to the steels to be tested: Rake angle α will be $+10°$; peripheral cutting speed, 400 ft. per min.; feed per revolution (dimension t_1 of Fig. 1), 0.0018 in.; wall thickness of tube (dimension w_1 of Fig. 1), 0.25 in.

Five successive cuts are made, the tool being sharpened after each cut. Readings of F_c and F_t are taken each time; a section of chip is collected whenever force readings are made. These chips

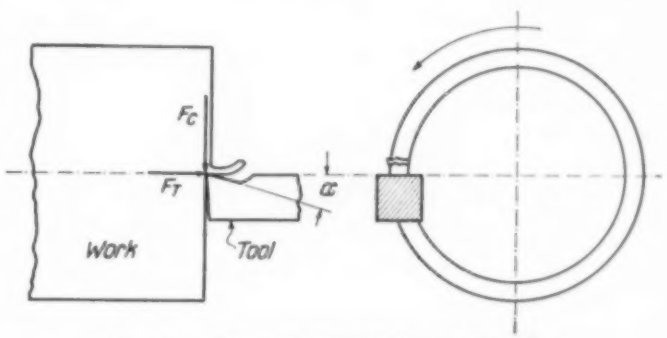


Fig. 5 — Convenient Test Setup That Provides the Simple Set of Geometrical Conditions Required for the Alignment Charts

are weighed, their length measured, and the weight per unit length is figured. Our friend averages the data for the five runs. Here is the result:

	Steel A	Steel B
Force component, F_c	231 lb.	164 lb.
Force component, F_t	196 lb.	93 lb.
Weight of chip	160 mg. per in.	105 mg. per in.

Quite a difference in the forces and chips produced from a given setup! Now to find out why.

The figure for chip weight is tackled first; from it values for the shear angle ϕ can be found. This is done in two steps — first a quantity is obtained from Fig. 2 known as the cutting ratio, r_c, (this actually is the ratio of dimensions t_1 to t_2 in Fig. 1); then ϕ is found from this ratio. On the alignment chart of Fig. 2, the broken lines show the steps which the metallurgist goes through in using the chart to find values of cutting ratio for both steels. The cross-sectional area of all cuts (Scale 3) are the same; weight of chip is laid off on Scale 4 and lines drawn to intersect with Scale

Fig. 4 — Alignment Chart for Computing Friction Angle and Coefficient of Friction From Observed Force Components

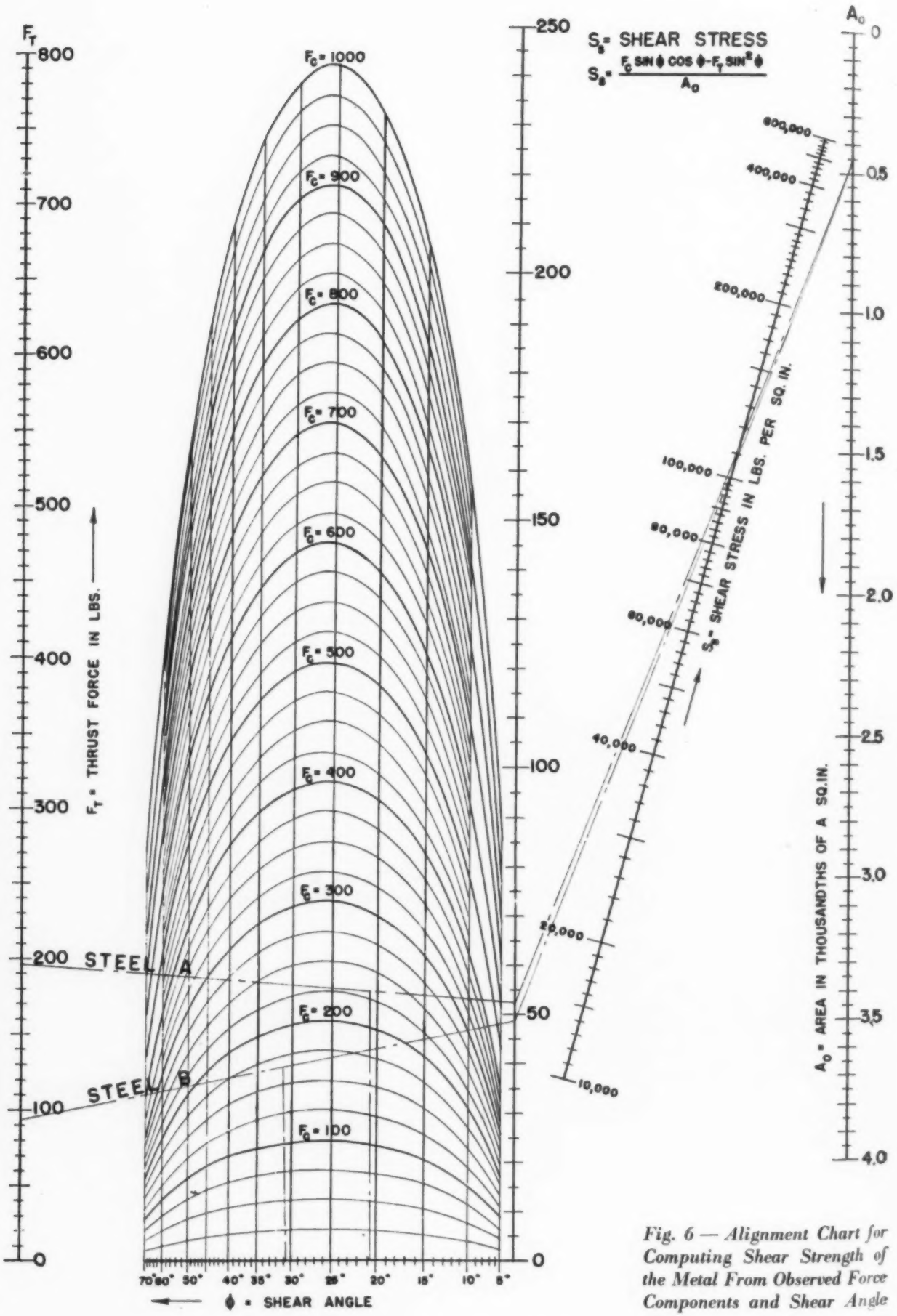


Fig. 6 — Alignment Chart for Computing Shear Strength of the Metal From Observed Force Components and Shear Angle

5. From the respective intersections lines are drawn through the point representing the specific gravity of steel on Scale 6 and the intersection of these lines with Scale 7 determines the cutting ratios, r_c.

He thus finds that for steel A $r_c=0.360$, and for steel B, $r_c=0.550$, and these two values are transferred to the left vertical scale in Fig. 3. The construction lines in Fig. 3 show how he uses these numbers to find the shear angle ϕ that actually existed when each metal was cut. (For steel A, $\phi=20.8°$; for steel B, $\phi=30.9°$.)

To use Fig. 4, he runs lines through the average experimental values from the dynamometer for F_c and F_t as shown; this operation yields values for $\tau-\alpha$. In addition, the actual coefficient of friction, μ, is found by extending horizontals across from the respective $\tau-\alpha$ values to an intersection with $\alpha=+10°$ (the rake angle), and then vertically down to the horizontal axis.

The series of operations shown by the broken lines of Fig. 6 give values of shear strength for steels A and B. Shear angles and values of F_c for the two steels (determined from Fig. 3 and dynamometer readings, respectively) locate the two points in the central curved space, and through which lines are drawn from F_t (scale at left) to the scale at center, and thence to the common point representing the area of metal removed from the test piece. Shear stress is determined by intersections of these two construction lines with the inclined scale in Fig. 6.

Finally, our metallurgist friend puts his figures for ϕ and τ into equation (1) along with the value of $+10°$ for the rake angle α; this gives him values for C. When he tabulates all these results and leans back in his chair to study them, this is what he sees:

	Steel A	Steel B
ϕ	20.8°	30.9°
μ	1.20	0.82
τ	50.3°	39.5°
C	81.9°	91.3°
S_s	115,000 psi.	106,000 psi.

At last it is plain why these two steels machine so differently in spite of their similar metallurgy; now the metallurgist knows the source of the differences. The friction μ between the tool and the flowing chip is much higher with the poor steel, A, than with the good steel, B (for A, $\mu=1.20$; for B, $\mu=0.82$). The poor steel, A, also has a much smaller value for angle C (81.9°) than does the good steel, B (91.3°). This is why the shear angle is low and the forces high when cutting the less machinable steel. The difference seems all the more striking to our metallurgical friend when he notes that the shear strengths of the two steels (under the conditions present in cutting) are practically equal.

And so our hypothetical problem has been solved. Of course the problems that arise in practice will seldom be as straightforward as this one. There usually will be differences in metallurgy, but as yet there are no numbers to evaluate such differences. There will be other variables present besides those talked about here; as yet the effect of these is not known. In spite of all this, however, the metallurgist will doubtless see that there is value in a test of the kind described. Much information of use in comparing and improving metals can be gained from it.

In conclusion, a word of caution is in order. It should be plain to the reader that there must be omissions of fact and departures from rigor in an article of this type, for the sake of clarity and brevity. The main purpose of the article is to show what can be done with the methods talked about; details of how and why are not complete. For this reason, it is suggested that those who wish to make use of these methods to obtain quantitative results should go to the original references cited earlier in this brief presentation.

Fig. 7 — Mechanical Tool Dynamometer in Use With Setup of the Type Sketched in Fig. 5

By C. H. Lorig*
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A New Method for Melting Magnesium

DURING 1944 and 1945 considerable work was done on a project that started out as an investigation of the comparative properties and advantages of the commonly used American and European casting alloys of magnesium. This was so intimately bound up with the soundness of the casting it was inevitable that the study should be extended to the problem of "microporosity" of magnesium castings, the relative susceptibility of the common alloys to its formation during controlled foundry operations, and the various commercial steps that could be taken to reduce it. It was in the latter phase of the studies that a new method of metal preparation was devised.

Prior to the beginning of this project, the commercial method of melt preparation consisted, briefly, of melting the metal under a cover of Dow 230 type flux in a bulk melter of 1500 to 2000-lb. capacity, and raising the temperature to 1250 to 1300° F. This metal is then transferred to refining pots holding from 60 to 500 lb. where, at a temperature of approximately 1325° F., it is "refined" by stirring in a Dow 310 type of flux, after which the melt is superheated to approximately 1650° F. to obtain grain refinement. The melt is then cooled to the pouring temperature, commonly to 1450 to 1480° F., and poured immediately.

It is recognized that the gas contained in the melt has a considerable influence on the amount of microporosity formed, and a wedge casting was devised to evaluate the susceptibility of the American and European alloys to this common ailment. Accordingly, the height of sound metal in the wedge casting was used as a means of measuring the gas content of the melt.

It is well known that hydrogen is about the only common gas which dissolves in magnesium to any appreciable extent, and it was confirmed by appropriate extractions and gas analyses that the gas causing the increase in the microporosity in the wedge casting was hydrogen. The principal source of this hydrogen was the moisture in the refining flux which was stirred into the melt, but this could be somewhat reduced by proper care in the "refining" operation. Moisture in chemical combination with or adsorbed on the surface of scrap and ingot was also a considerable source of gas, and this could be partially eliminated by adequate preheating prior to melting. Presumably, also, gas can be absorbed from the moisture in the atmosphere, from the products of combustion, or from moisture which is on the surface of tools and equipment which might contact the molten metal. Apparently, however, gas absorption from the green sand mold was not very important.

While gas from these sources could be minimized by very careful melting technique, it was found that the most reliable method of producing a melt of low gas content consisted of fluxing the melt with chlorine, approximately a 15-min. period being required for the introduction of the fluxing gas. This method of metal treatment cleaned and degassed the metal far more effectively and reliably than the conventional method. Furthermore, the operation was somewhat more simple and less labor was required. This procedure, then, appeared to be a very practical substitute in place of the so-called refining flux of the Dow 310 type, and it caught on quickly in commercial foundries.

It was also noted early in the work on this project that the introduction of a carbonaceous gas,

*Mr. Lorig was "official investigator" on Research Project Contract W.P.B.-135 between Battelle Memorial Institute and the Office of Production Research and Development, War Production Board. James A. Davis, L. W. Eastwood, James DeHaven and F. W. Fink were research engineers on the project. Work was underway from Nov. 1, 1943, until Sept. 29, 1945, and reports total 400 typewritten pages. The final and summary report is on file in the Office of Technical Services, Department of Commerce, Washington, D. C., and is indexed as P.B.-19771.

such as dried natural gas, acetylene, or carbon dioxide, would refine the grain without any superheating operation. This observation was extended, and it was found in general that any material containing carbon will produce grain refinement.

A prerequisite to the successful use of the superheating operation is a substantial aluminum content in the melt, and this same limitation holds for the use of carbon as a means of refining the grain. Since aluminum and carbon were both necessary, it was suggested that the active grain refining constituent may be aluminum carbide.

This led to investigations of various carbides, including aluminum carbide, silicon carbide, manganese carbide (in the form of a high carbon, high manganese ferromanganese), as well as powdered and granulated forms of graphite and carbon. All of these were reasonably successful, though the success depended to a considerable extent upon the contact obtained between the solid carbide or carbon and the melt; unless these materials were added properly, erratic results were obtained. These solid materials, therefore, did not appear to be useful for commercial foundry practice.

Contact of molten metal with silicon carbide, by melting it in a Tercod or silicon carbide crucible, consistently produced fine-grained castings without any superheating operation. However, the silicon carbide crucibles have the limitation that they are penetrated by the flux, and rapidly deteriorate. It is possible, however, that with continuous operation, such crucibles might be quite successful in a bulk melter. Silicon pickup was minor, and even this could be entirely eliminated by using a carbon lined crucible.

The next step in obtaining grain refinement by means of carbon consisted of the use of organic chlorides. Such materials will react with the magnesium to form magnesium chloride and free carbon in a very fine or atomic state of division readily absorbed by the melt. It was found that such organic chlorides were, in fact, a reliable means of refining the grain of castings.

Solid organic chlorides can be added to the melt after fluxing with Dow 310 or with chlorine by plunging small cakes of it into the melt with an inverted cup or wire. Grain refinement is then obtained without superheating or any other grain refining operation. Furthermore, it was found that, if the contact of the organic chloride with the magnesium was sufficiently prolonged, it also cleaned and degassed the melt.

However, the mechanical difficulties of adding solid organic chlorides make it impractical for the simultaneous cleaning, degassing, and grain refining operation. Accordingly, carbon tetrachloride was introduced into the chlorine by bubbling the latter through a bath of carbon tetrachloride, maintained at 80° F. or slightly above. The chlorine gas then carried over a sufficient quantity of carbon tetrachloride vapor to effect simultaneous cleaning, degassing, and grain refinement in one operation in a very simple manner. About 0.25% of carbon tetrachloride and 1 to 1.5% of chlorine are entirely adequate for this operation.

Based on somewhat limited data, it was found that if this operation is conducted in the foundry the optimum melt temperature is 1250 to 1275° F. for gas cleaning. However, temperatures up to 1450° F. are also workable. The preferred method consists of the treatment of the metal with the combination of chlorine and carbon tetrachloride prior to the initial casting of the ingot. When such carbon treated ingots are remelted the castings are still fine grained; in fact only 25% of such carbon treated ingot need be used in the total charge in the foundry.

This procedure has worked satisfactorily on a laboratory scale, but had not been given a plant test on a commercial scale at the date of termination of the research contract (Sept. 29, 1945).

Carbon treated melts produce coarse-grained castings when the melts are held at a low temperature (near 1250° F.) for a few minutes; in this respect, they are entirely similar to superheated melts. However, the fine grain produced by carbon treated melts can be restored by merely reheating the melt to a proper pouring temperature. Gently stirring is usually effective in producing even slightly finer grain. Superheated melts, on the other hand, cannot be reliably restored to fine grain once they are coarsened by holding at a low temperature, although reheating to the pouring temperature and gently stirring will usually also partially refine the grain.

Some phosgene, $COCl_2$, forms at the melt surface and escapes with the chlorine. The quantity of chlorine in the escaping gas is several hundred times the phosgene concentration, and any method which successfully removes the chlorine will also remove the phosgene. Likewise, if the phosgene were present in slightly harmful quantities, the chlorine concentration would be lethal. This ventilation problem is successfully handled in aluminum foundries, and consequently should cause no danger to workmen or nuisance to neighbors when practiced by a magnesium foundry.

The method of melt preparation described above is apparently applicable to large melt quantities, consisting of 1500 to 2000 lb. of metal, such as those ordinarily produced in the bulk melter. The ordinary refining pot used in commercial foundries could therefore be eliminated. However, it is desirable to have a method of transferring

metal from the bulk melter to a pouring ladle (or directly to the mold) which is simple, economical, and minimizes damage to the metal during the transfer. It is obvious that transfer to a pouring ladle by pouring from one container to another might introduce gas or cause some contamination with oxides or flux.

Accordingly, the centrifugal, air-driven pump commonly used in the ingot shop was modified for use in foundry operations by making this transfer equipment suitable for operating at the higher temperatures of 1500 to 1520° F. as a maximum, and by making it suitable for intermittent operation such as would be encountered when pouring a series of molds from a 2000-lb. melt. Such transfer from the bulk melter directly to molds would be practicable only in those foundries which are equipped with a continuous conveyer to transport the molds to a pouring station some 10 or 12 ft. in front of the bulk melters. Standardization of pouring temperature is generally required in those foundries so mechanized, but this is satisfactorily done by paying proper attention to the selection of castings and designs poured on a single mold conveyer at a given time. It would also be quite feasible to transfer directly to a pouring ladle, using a transfer metal temperature at the maximum pouring temperature required. Melts could then be cooled to any pouring temperature merely by holding, and then be poured directly into the molds wherever they may be, independent of the degree of mechanization in a given foundry.

The metal transfer pump consists of a vertical shaft with a centrifugal pump in a suitable housing at the bottom and an air-driven motor at the top, the speed of which can be regulated by the volume of air supplied to it. However, because of the higher temperatures involved (1250° F. for casting ingots, about 1550° F. for pouring castings) the hot portions of the pump were constructed of heat resisting material. A 1-in. tube, also made of heat resisting steel, was attached to the discharge, so arranged that it would have vertical clearance over the edge of the pot and extend outward horizontally to a point convenient for molds or transfer ladles. This tube makes a sharp return at its outer end, and at this bend is a ½-in. valve which can be opened, partially or fully, when metal is to be drawn off. The valve itself is very simple, merely consisting of a tapered metal plate running in appropriate slides. Its lower end is cut to form a ½-in. semicircle, so that the opening passes an oval shaped or circular stream of metal. This valve is independently heated, along with the transfer pipe, as described later.

When the pump is in operation, metal is circulated in the pipe, which forms a closed system without contact with the atmosphere. When molds are poured or ladles are filled, the speed of the air motor is increased, and the valve in the return bend is opened, whereby a portion of the pumped metal discharges under very slight pressure. The metal not used is returned in the return pipe, which is, of course, maintained full at all times by atmospheric pressure. This system provides metal at the discharge or valve end with little or no hydrostatic pressure, but the pump lines are never permitted to become empty until the useful contents of the pot have been discharged. In commercial operations neither the pouring ladles nor the bulk melter would be entirely emptied unless operations were to be discontinued.

In order to avoid the possibility of poor temperature control and freezing of the liquid prematurely in the pipe, it is necessary to operate both the discharge and return pipe in a gas fired tubular furnace, extending the entire length of the pipe. In this way the pouring temperature can be exactly regulated by the temperature of the melt in the pot, there being no loss in temperature during transfer.

The entire transfer mechanism, consisting of the tubular furnace with its burner, discharge, return pipe, and the pump, can be constructed into one assembly. This entire transfer assembly is supported by means of an overhead crane, and a small air hoist attached for raising and lowering the discharge end slightly, or swinging to right or left to accommodate various heights and positions of pouring boxes or ladles. The entire transfer equipment may also be moved from one melting furnace to another.

Any such method of metal transfer requires some modifications for individual foundries. For example, the diameter of the pipes would be increased for pouring large molds. There is also the question, of course, of proper pouring temperatures if molds of various sorts are poured directly from the melting furnace. This inflexibility applies also to foundries in which the molds are transported by means of conveyers to the furnace room. It is quite likely, however, that most castings can be poured successfully at 1460 to 1480° F. There are some molds which foundrymen prefer to pour "two up"; that is, from two pouring ladles. Such molds would have to be poured from metal transferred to pouring ladles, or two transfer units would be required from adjacent furnaces; the third possibility would be to use a pouring trough on top of the mold which introduces metal into two or more sprues simultaneously from a single pump discharge. Such pouring troughs are found in many aluminum foundries.

Forging Alloy Steel Radial Engine Crankcases

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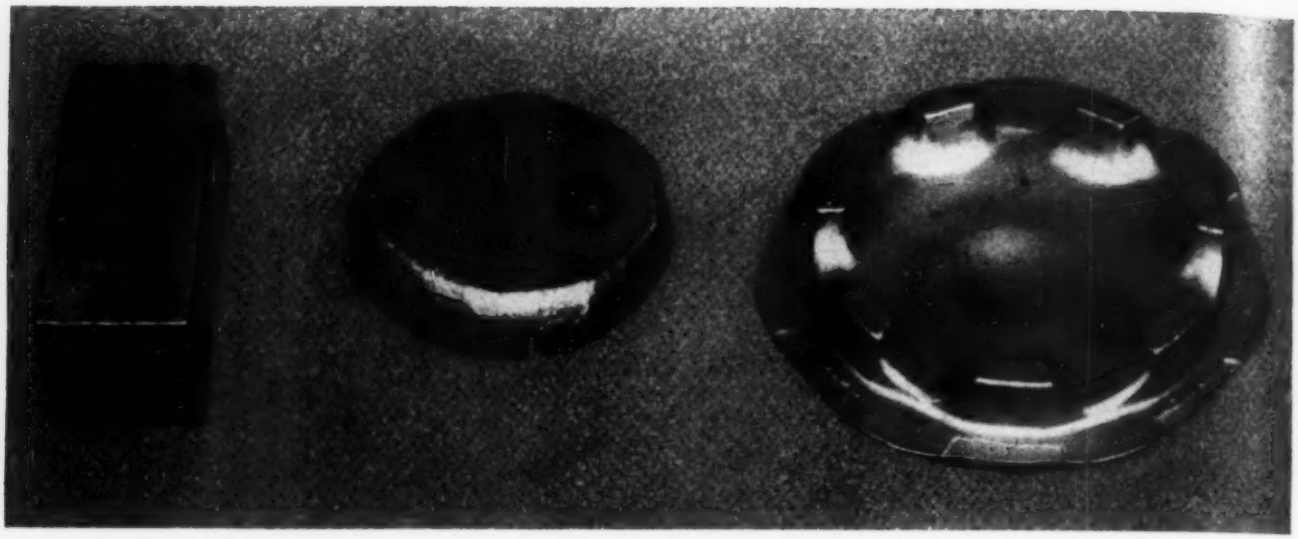
IN *Metal Progress* for June 1945 the present authors discussed in some detail the "Metallurgical Aspects of Alloy Steel Aircraft Engine Forgings". This contribution can be regarded as a supplement, in that it describes pictorially the principal operations in forging one of the largest and most difficult parts coming within the above category. The photographs reproduced (except as noted individually) are the work of R. Stranieri.

One of the most interesting as well as largest aircraft forgings is this alloy steel, radial engine crankcase. Many crankcases for single-row engines were forged from an aluminum alloy. The steel crankcase to be described represents an interesting change in aircraft engine design which reverses, in part, the present trend toward the use

Photo by William T. Lyon



A — Multiple B — First Breakdown C — Blocked

Forging Sequence A, B and C on Steel Crankcase

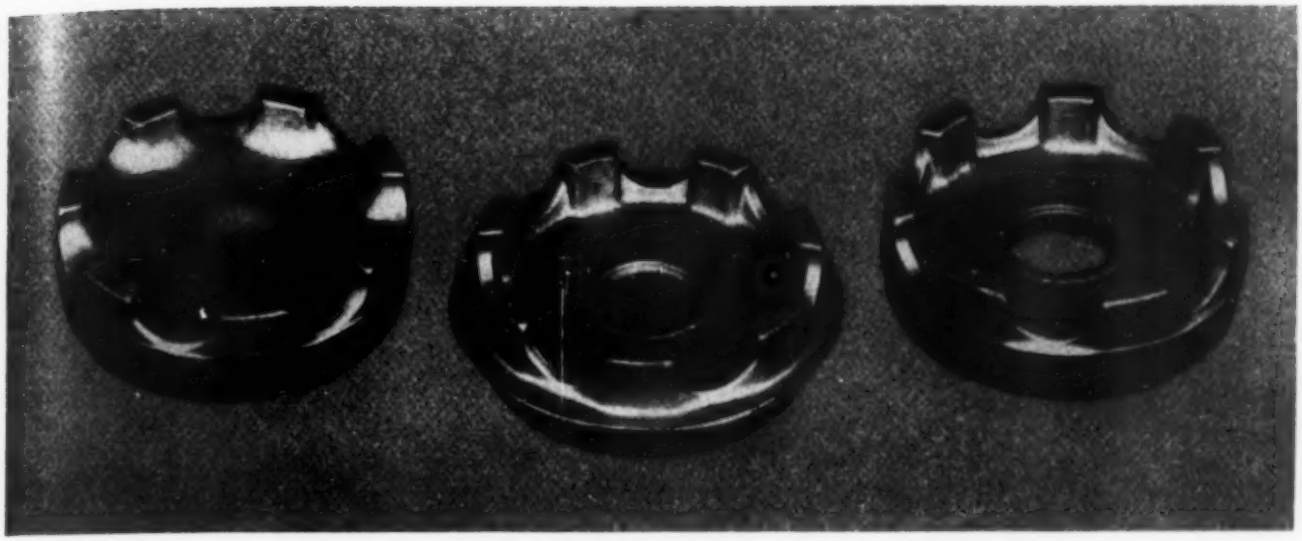
of strong forging alloys of the light metals. The steel crankcases are stronger and actually lighter than the aluminum crankcases they replaced. Other advantages claimed by their designers and users are that they extend engine life and facilitate maintenance.

Crankcases for the single-row radial engine are made up of two sections, while double-row radial engine crankcases are made up of three sections — front, center and rear. The photographs on pages 1026 to 1028 outline the manufacture, by the three-hammer method, of the rear section for a 14-cylinder, double-row radial engine. These crankcases are also made in two hammers, and sometimes in a single hammer of 35,000-lb. capacity. The finished forging made as illustrated uses less raw steel, is considerably lighter in finished weight, and has superior grain flow compared to crankcases made by other methods.

The six steps shown across the top of these two pages show the forging sequence from the billet multiple to the finished forging. The steel used is A.M.S. 6324, a national emergency, chromium-nickel-molybdenum steel with hardenability approximately equivalent to the S.A.E. 4140 from which the crankcases were formerly made.

Photo by William M. Rittase

The 8½-in. square billets are saw cut in hydraulic feed, power hack saws into multiples of the proper weight tolerance (Sequence A) so that the finished forgings will be filled with a minimum of waste through the flash. Each multiple is weighed on a platform scale and then it proceeds on a roller conveyer to an alternating current magnaflux station, Fig. 1, page 1026, where prod contacts are used to examine each piece on one saw-cut end. Each multiple is magnafluxed and inspected in two directions perpendicular to each other. This test serves to reveal any center discontinuity such as snow flakes or thermal ruptures, heavy segregation,



D — Blocked and Trimmed E — Finish Forged F — Trimmed

Forging Sequence D, E and F on Steel Crankcase

or gross porosity. Defective material revealed by this test is scrapped immediately.

Multiples are segregated and processed by heat lots. They are heated in a 17-ft. rotary forging furnace to approximately 2200° F. for the first hammer operation. This furnace as well as all the other rotary forging furnaces used for heating the crankcase forging are not only temperature controlled, but are also time-cycle controlled. In addition, periodic temperatures are taken on the stock, as it is forged, with an optical pyrometer.

Heated multiples are upset on flat dies in a 9000-lb. hammer, Fig. 2, into the disks shown as Sequence B, above. This disk is reheated to approximately 2200° F. in a rotary furnace and blocked to rough-form the crankcase (Sequence C) in a 20,000-lb. hammer, Fig. 3. This blocked form is then trimmed in a hydraulic press, leaving it in the shape as revealed in Sequence D.

The rough-formed crankcase is given a final wash heat at 2200° F. in a rotary furnace, after which it is finish forged in a 20,000-lb. hammer, Fig. 4 (page 1027). The crankcase after this operation is shown as Sequence E, above. The flash is trimmed and the center punched out on a mechanical press, Fig. 5, page 1027. The finished crankcase, Sequence F, is then returned to the finish 20,000-lb. hammer and struck one light blow in the die, Fig. 6, to eliminate any distortion from the previous hot trimming operation.

Crankcase forgings are annealed for machinability to a maximum Brinell of 228, and are then rough machined, Fig. 7, prior to final heat treating. The rough machined crankcases are heated to 1575° F. in continuous furnaces, Fig. 8, either gas or oil fired, and are quenched in highly agitated oil at approximately 140° F. The crankcases are removed from the quench while still warm, about 200° F., and are charged directly into a continuous, recirculating draw furnace. The draw furnace temperature is so regulated as to temper the forgings to a surface Brinell range of 255 to 286. Periodic Brinell tryout tests are made at the start and during the heat treat run. At least one crankcase from each heat is cut up for studying the hardness penetration.

The heat treated parts are shot blasted, then conveyed through inspection, and checked for

Photo by Van Fisher

hardness in several places on Brinell machines, Fig. 9, page 1028, after which they are ready for shipment.

Such rough machined and heat treated crankcases are further processed by the engine builder by machining all over, and grinding and polishing to remove all tool marks. To insure accurate alignment of all parts the front, center and rear sections are assembled into a single unit for final machining.

Fig 1 (Above) — Sawed Multiples Move on Roller Conveyer to Station Where Prod Contacts Magnaflux Each Piece in Two Perpendicular Directions

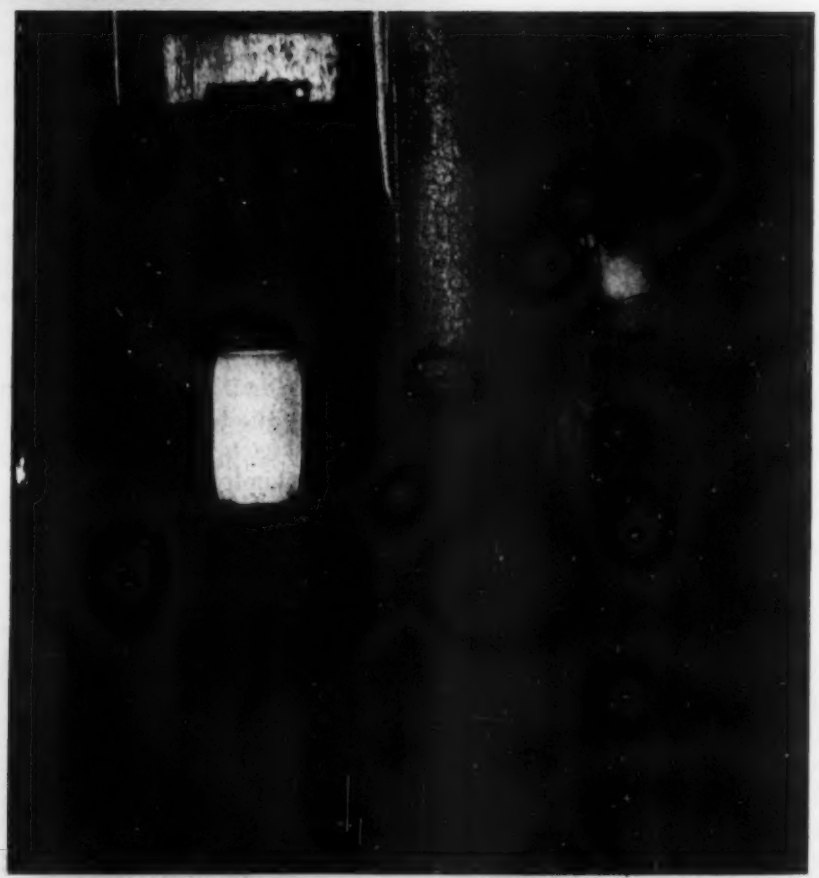


Fig. 2 (Left) — The First Hammer Operation, on Flat Dies, in a 9000-Lb. Hammer, Upsets the Multiple to a Disk for the Blocker Dies

Fig. 3 (Below) — The Next Hammer Operation, in a 20,000-Lb. Hammer, Rough Forms the Crankcase Preparatory to Final Shaping

Fig. 4 — The Blocked Forging Is Reheated to 2200° F. in a Rotary Furnace and Finish Forged in a 20,000-Lb. Hammer

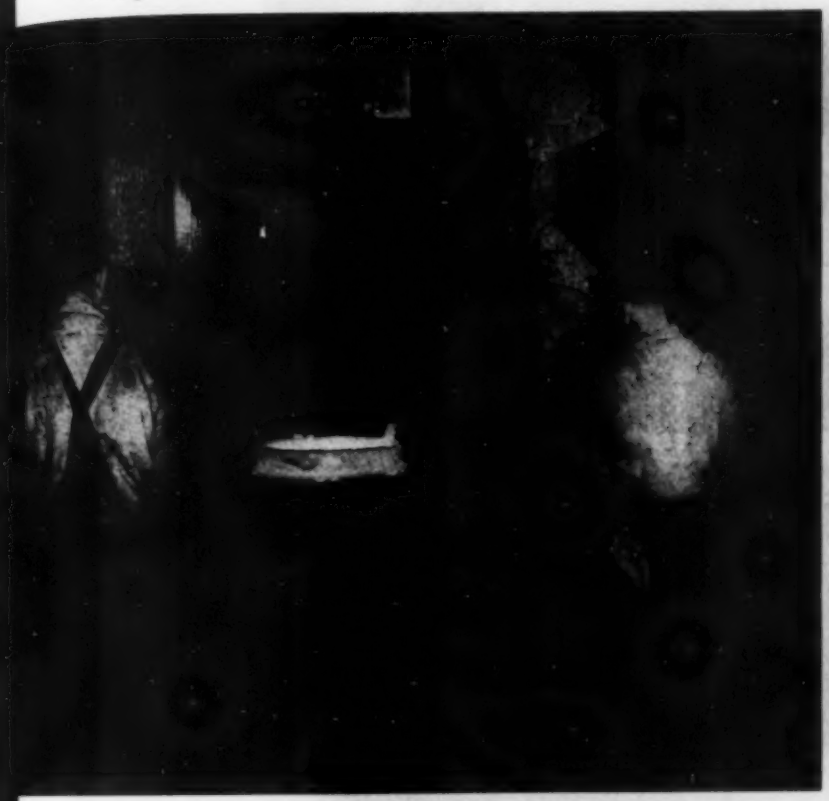


Fig. 5 — Flash Is Removed and Center Hole Punched Out on Mechanical or Hydraulic Press

Fig. 6 — After Trimming, the Forging Is Replaced in the Finish Dies and Struck One Light Blow to Straighten

Fig. 7 — Crankcase Forgings Are Annealed to 228 Max. Brinell, and Are Rough Machined Before Hardening

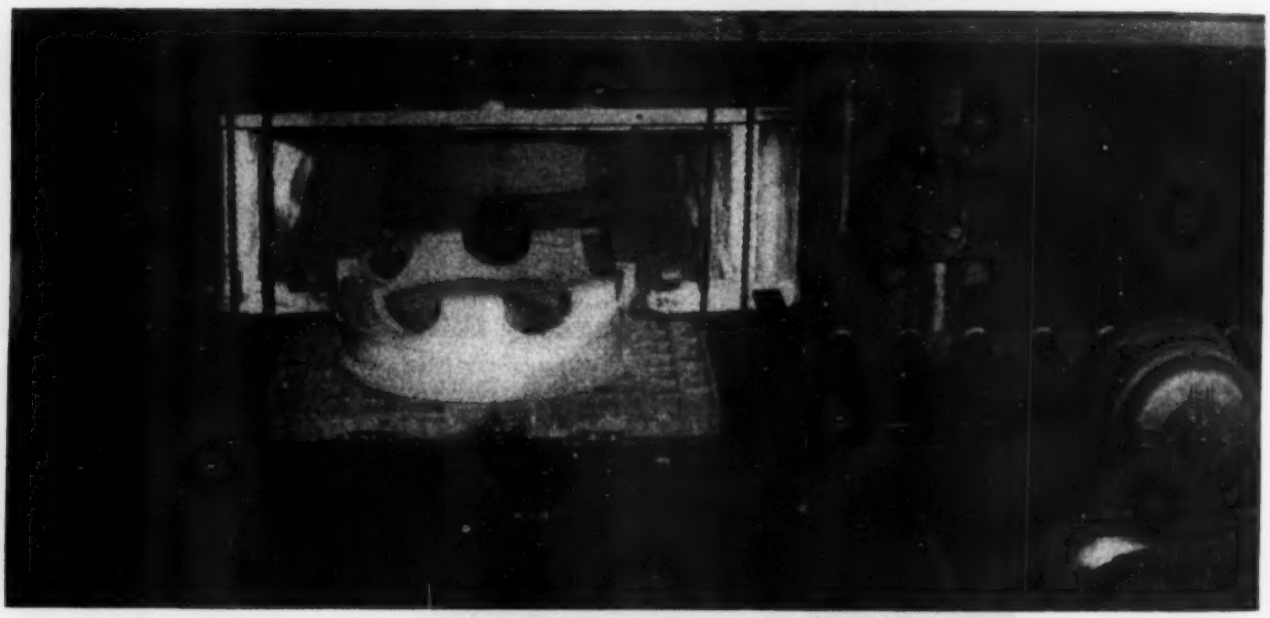


Fig. 8 (Above) — Machined Crankcases Are Heated to 1575° F. in a Continuous Furnace and Quenched in Propeller Agitated Oil at About 140° F. The warm forgings are placed in a continuous draw furnace and are tempered to a surface Brinell hardness of 255 to 285

Fig. 9 — Heat Treated Forgings Are Shot Blasted, Then Conveyed Through Inspection and Brinell Stations Where Hardness Is Checked in Several Places

METAL-CUTTING LUBRICATION

Tool Life Increased 50% with Improved Cutting Oil

TRANSPARENT, STAIN-PROOF OIL PRODUCES GRATIFYING RESULTS

Lubrication Engineer's Report

We knew from certain operating conditions on a Landis automatic threading machine at a prospect's plant* that we could do a better job with Chillo No. 3 than was being done with a competitive product having approximately 14% lard and 1% sulphur compound.

"The operation being performed was threading 14 to 16 foot bar stock from all grades of materials as to hardness and all sizes from ½ inch to 2 inches. On 16 foot bars of 1 inch, 1¼ inches and 1½ inches dimensions the average output was four bars of 64 feet per chaser grind with the 14% lard and 1% sulphur compound oil, and on under one inch bars the average output was 6 bars or 96 feet. The average speed or RPM while threading was 50 to 64 on the one inch and over, while the average on the under one inch was 64 to 84, depending on the hardness of the metal.

"Although the threads were good and acceptable with the oil in use, we produced a much more uniform and smoother thread with Cities Service Chillo No. 3. We increased the tool life from four bars on the one inch and over to six and sometimes seven or an average of 100 feet per chaser grind. The under one inch production per chaser grind was increased to nine bars or approximately 140 feet.

Tool Life Increased

"We stepped up production by increasing the RPM on the under one inch bars to 84, 90, or 106, depending on the hardness, and increased the larger stock bars to 64 and 84 RPM.

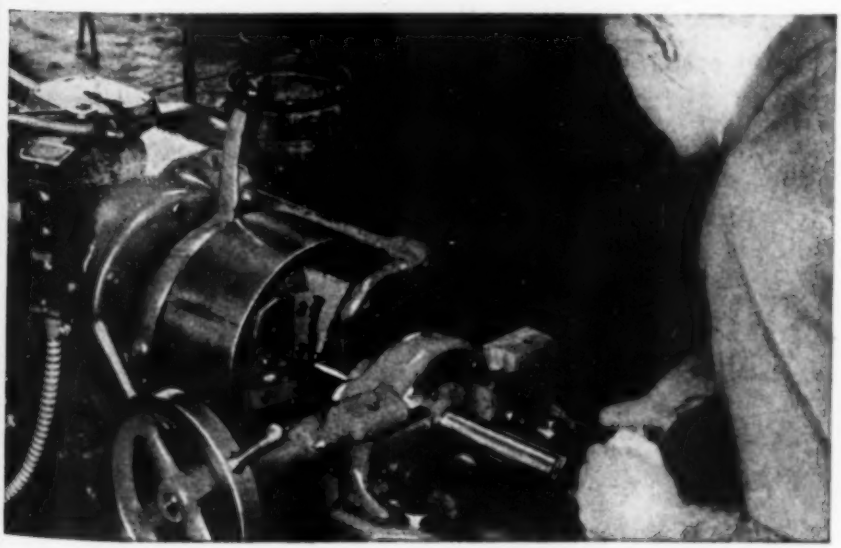
Production Stepped Up

"We were requested to supply a transparent oil that would not leave stains on the finished product. With this in mind and knowing that the plant would be very critical should some work become stained, we recommended Chillo No. 3 for the job with very gratifying results."

Cities Service makes available to any industrial organization operating in its marketing territories East of the Rockies, a highly specialized lubrication engineering service. If you're facing a metal-working problem—don't delay—call your local Cities Service office (in the South call Arkansas Fuel Oil Company), or write to Cities Service Oil Company, 60 Wall Tower, New York 5, N. Y.

Engineering Service Available

*Name on request.



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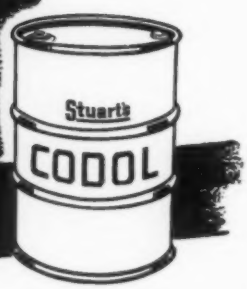
★ Longer Wheel Life



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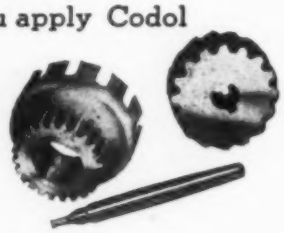

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Stuart Oil Engineering Goes With Every Barrel

Underwater Cutting*

STEEL can be cut with ease by divers working under water and at a speed equal to surface cutting. Cast iron and nonferrous metals can also be cut but at a somewhat reduced speed. The most widely used cutting methods are:

1. Gas cutting — *(a)* oxy-acetylene (limited to a depth under 20 ft.); *(b)* oxy-hydrogen (suitable for any thickness at any depth).

2. Electric cutting — *(a)* arc-oxygen with carbon, tubular steel or tubular ceramic electrodes; *(b)* metallic-arc with a solid steel electrode (limited in speed and thickness of metal).

Underwater welding with the metallic arc is the only process in use at this time.

The basic principles of an underwater gas cutting torch are simple. Acetylene gas is generally not recommended. For efficient operation, the discharge end of the air nozzle must supply the compressed air, which provides half the oxygen needed for combustion, without creating turbulence and without contaminating the purity of the oxygen delivered through the central orifice of the tip. The underwater cutting torch must be made of tough, noncorrosive metals since it is subject to more rigorous working conditions than a surface torch. Underwater gas torches are most frequently ignited on the surface.

In the arc-oxygen process, the electrode may be a carbon or graphite rod, with one or more metal tubes in it, or a hollow ceramic rod or a covered steel tube. Regardless of the type, it must be fully insulated and thoroughly waterproofed. The hollow carbon electrode has given way to a large extent to more effective gas cutting methods and to easier-to-use tubular steel electrodes. The electrode lasts about 20 to 30 min. in operation and must be returned to the surface for replacement.

Tubular steel electrodes are easy to use and the electrodes can be changed under water. The process can be employed under water for cutting cast iron and nonferrous metals as well as steel. It may also be used in the open air for cutting difficult high alloy steels, cast iron and nonferrous metals. *(To p. 1032)*

★Abstracted from "Underwater Cutting and Welding", by Charles Kandel, *Welding Journal*, V. 25, March 1946, p. 209 to 211.

WEAR ON CAST GEARS
BETTER TOOL LIFE AND FINISH
DRAW BENCH LUBRICATION
IMPROVING FINISH ON CASTINGS
MAGNESIUM AND ALUMINUM FORMING

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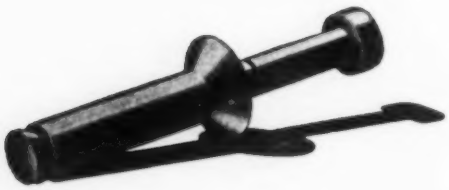

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SPECIAL CHARACTERISTICS establish Cherry superiority over other blind fasteners: (a) Greater shank expansion (b) Greater allowable variance in material thickness for a given grip-length.

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Cherry Rivet Company

LOS ANGELES 13, CALIFORNIA

Underwater Cutting

(Continued from page 1030)

Tubular ceramic electrodes, consisting of hollow rods of silicon carbide or other ceramic material, are in general used in the same way as tubular steel electrodes. Each electrode will burn for about 10 min., so not as much time is lost in changing electrodes as with the more rapidly consumed steel rods. Also, because of the larger cross section, heavier currents may be used.

Solid steel electrodes with extruded and waterproofed coatings may be used for underwater cutting. Equipment the same as that used for underwater welding is employed. The Craftsweld arc-oxygen underwater cutting torch may also be modified for use.

With a proved electrode specially engineered for the purpose, properly coated and fully waterproofed, it is possible to make welds

under water on mild steel. Properly done, underwater welding will develop 80% of the tensile strength and 50% of the ductility as compared to the same welds on the surface. Fillet welds are most suitable. The operator must be trained and the work requires more time and greater care and skill than on the surface. Its speed is limited only in the same sense as any other mechanical operation carried on under water. The equipment is identical with that used for cutting except that a fully insulated underwater electrode holder and suitable welding electrodes are substituted for the cutting torch and the cutting electrodes.

In all types of underwater cutting, special safety precautions are required in addition to those necessary for cutting and welding in the air. Principal among these are special attention necessary to prevent short circuits, either in the equipment or through the diver's gear.

Standard Tolerances for Forgings up to 100 Lb.

Summary of Standards Adopted by Drop Forging Association, 1937

TOLERANCES, within the scope of these standards, shall be either "special" or "regular."

Special tolerances are those particularly noted on the drawings or in the specifications, and apply only to the particular dimension or thing noted. They may state any or all tolerances in any way as occasion may require. Regular tolerances apply in all other cases.

Regular tolerances in general forging practice are known as (*a*) "commercial standard," for general forging practice, or (*b*) if extra close work is desired involving additional expense and care in the production of forgings, "close standard" may be specified.

Class I—Thickness Tolerances

For drop hammer forgings, thickness tolerances shall apply to the overall thickness measured in a direction perpendicular to the fundamental parting plane of the dies.

For upset forgings, thickness tolerances shall apply to the metal actually enclosed and formed by the dies, measured parallel to the direction of travel of the ram.

Thickness Tolerances in Inches

Max. Net Weight	Commercial		Close	
	Minus	Plus	Minus	Plus
0.2	0.008	0.024	0.004	0.012
0.4	0.009	0.027	0.005	0.015
0.6	0.010	0.030	0.005	0.015
0.8	0.011	0.033	0.006	0.018
1	0.012	0.036	0.006	0.018
2	0.015	0.045	0.008	0.024
3	0.017	0.051	0.009	0.027
4	0.018	0.054	0.009	0.027
5	0.019	0.057	0.010	0.030
10	0.022	0.066	0.011	0.033
20	0.026	0.078	0.013	0.039
30	0.030	0.090	0.015	0.045
40	0.034	0.102	0.017	0.051
50	0.038	0.114	0.019	0.057
60	0.042	0.126	0.021	0.063
70	0.046	0.138	0.023	0.069
80	0.050	0.150	0.025	0.075
90	0.054	0.162	0.027	0.081
100	0.058	0.174	0.029	0.087

Class II—Width and Length Tolerances

Width and length tolerances shall be alike, and are classified in three subdivisions (*a*) shrinkage and die wear tolerance, (*b*) mismatching tolerance, (*c*) trimmed size tolerance.

For drop hammer forgings, width and length tolerances shall apply to the metal actually enclosed and formed by the die, as measured parallel to the fundamental parting plane of the dies.

For upset forgings, width and length tolerances shall apply to directions perpendicular to the direction of travel of the ram.

II(a)—Shrinkage and Die Wear Tolerances

See table below. These shall not be applied separately, but only as the sum of the two; they shall be measured in such a way as to eliminate draft or variation in draft. They apply to that part of the forging formed by a single die block, and to no dimension crossing the parting plane.

Shrinkage and Die Wear in Inches

Length or Width	Shrinkage			Die Wear	
	Commercial + or −	Close + or −	Max. Net Weight	Commercial + or −	Close + or −
1 in.	0.003	0.002	1 lb.	0.032	0.016
2 in.	0.006	0.003	3 lb.	0.035	0.018
3 in.	0.009	0.005	5 lb.	0.038	0.019
4 in.	0.012	0.006	7 lb.	0.041	0.021
5 in.	0.015	0.008	9 lb.	0.044	0.022
6 in.	0.018	0.009	11 lb.	0.047	0.024
For each additional inch add	0.003	0.0015	For each additional 2 lb. add	0.003	0.0015
For example:			For example:		
7 in.	0.021	0.011	13 lb.	0.050	0.026
12 in.	0.036	0.018	21 lb.	0.062	0.031
18 in.	0.054	0.027	31 lb.	0.077	0.039
24 in.	0.072	0.036	41 lb.	0.092	0.046
36 in.	0.108	0.054	51 lb.	0.107	0.054
48 in.	0.144	0.072	71 lb.	0.137	0.069
60 in.	0.180	0.090	91 lb.	0.167	0.084

II(b)—Mismatching Tolerance

Mismatching is the displacement of a point in that part of a forging formed by one die block of a pair, from its desired position when located from the part of the forging formed in the other die block of the pair, measured in a projection parallel to the fundamental parting plane of the dies. It does not include any displacement caused by variation in thickness of the forging; mismatching tolerances are independent of and in addition to any others.

Mismatching Tolerance in Inches

Max. Net Weight	Commercial	Close
1 lb.	0.015	0.010
7 lb.	0.018	0.012
13 lb.	0.021	0.014
19 lb.	0.024	0.016
For additional 6 lb. add	0.003	0.002
For example:		
37 lb.	0.033	0.022
55 lb.	0.042	0.028
79 lb.	0.054	0.036
97 lb.	0.063	0.042

II(c)—Trimmed Size Tolerances

The trimmed size shall not be greater nor less than the limiting sizes at the parting plane imposed by the sum of the draft angle tolerances and the shrinkage and die wear tolerances.

Class III—Draft Angle Tolerances in Degrees

	Drop Forgings		Upset Forgings	
	Outside	Inside Holes	Outside	Inside Holes
Nominal angle	7	7 or 10	3	5
Commercial limits	0 to 10	0 to 13	0 to 5	0 to 8
Close limits	0 to 8	0 to 8	0 to 4	0 to 7

Class IV—Quantity Tolerances

Any quantity shipped within the quoted limits of over-run or under-run shall be considered as completing each release or part shipment of an order. Limits are as follows:

Quantity Tolerances

Number on Order	Over-run	Under-run
1 to 2	1 piece	0
3 to 5	2 pieces	1 piece
6 to 19	3 pieces	1 piece
20 to 29	4 pieces	2 pieces
30 to 39	5 pieces	2 pieces
40 to 49	6 pieces	3 pieces
50 to 59	7 pieces	3 pieces
60 to 69	8 pieces	4 pieces
70 to 79	9 pieces	4 pieces
80 to 99	10 pieces	5 pieces
100 to 199	10%	5.0%
200 to 299	9%	4.5%
300 to 599	8%	4.0%
600 to 1,249	7%	3.5%
1,250 to 2,999	6%	3.0%
3,000 to 9,999	5%	2.5%
10,000 to 39,999	4%	2.0%
40,000 to 299,999	3%	1.5%
300,000+	2%	1.0%

Class V—Fillet and Corner Tolerances

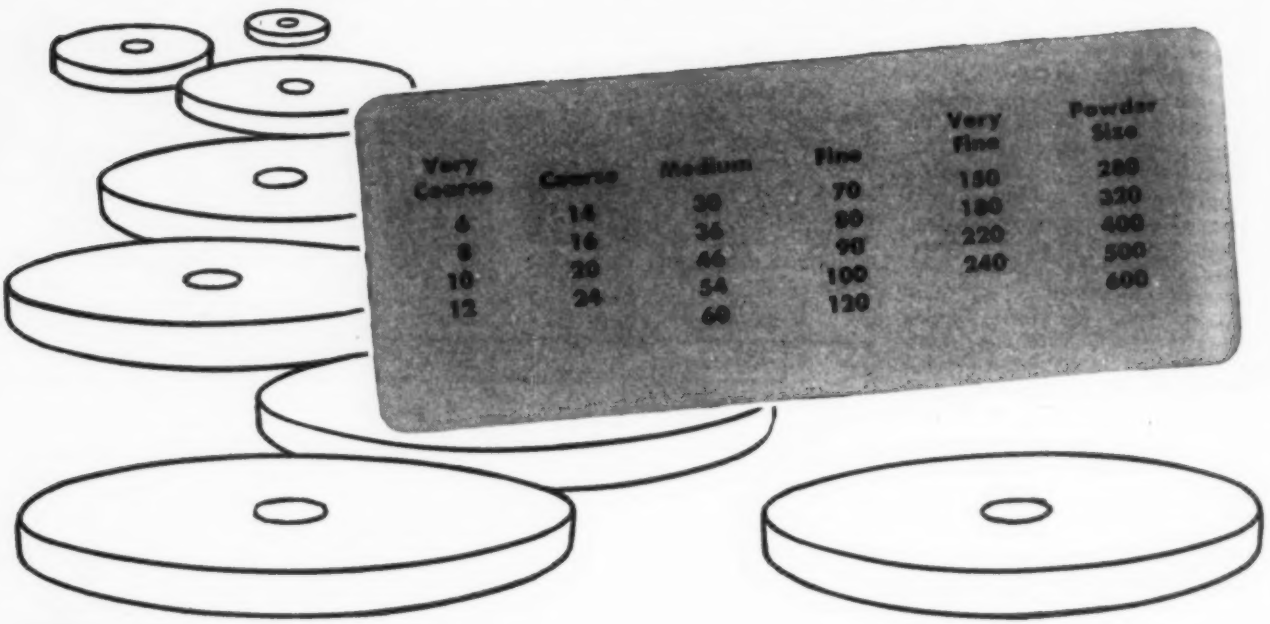
Fillet and corner tolerances apply to all intersecting surfaces even though drawings or models indicate sharp corners. If such drawings or models have or indicate (even though actual dimensions are not specified) fillet or corner dimensions of larger radii than the following standards, such larger dimensions shall be considered as actually specified and the tolerances shall be "special tolerances."

Where a corner tolerance applies on the meeting of two drafted surfaces, the tolerance shall apply to the narrow end of such meeting and the radius will increase toward the wide end. The total increase in the radius will equal the length of the drafted surface in inches, multiplied by the tangent of the nominal draft angle.

Fillet and Corner Tolerances

Max. Net Weight	Commercial	Close
0.3 lb.	3/32	3/64
1 lb.	1/8	1/16
3 lb.	5/32	5/64
10 lb.	3/16	3/32
30 lb.	7/32	7/64
100 lb.	1/4	1/8

How do you tell which grit to use?



Listed is a commercial classification of standard abrasive grit sizes. They come in a wide range... from 6 classified as very coarse to 600 classified as powder size. And, the variety is further extended by special sizes and combinations. Yet, each one is designed to do a specific job better than any of the rest.

To complicate correct choice even more, there is a long list of variable factors to consider. Among these, you'll find wheel speed, machine condition, specified tolerances, material analysis, related production schedules, and a host of others.

The correct selection hinges on the review which is given to all the controlling factors. Yet...grinding efficiency and economy depend on the right answer.

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Your nearest contact to this service is a CARBORUNDUM representative You'll find him willing and helpful. Through a sound knowledge of abrasives and first-hand experience of their use and application in the many plants he contacts, he is able to make intelligent recommendations and suggestions. On the more uncommon problems, he can even call on our Abrasive Engineers who are more fully qualified to tackle the tough problems. And, sometimes, the answer comes from the modern laboratories at CARBORUNDUM—where scientists and technicians probe for new information on abrasives, practices and developments.

Here is a sound approach—not only to getting the right grit—but the right combination of grit, bond, grade, structure and all the other parts that make up a grinding wheel. *Plus* knowledge and experience invaluable in modern grinding methods and procedures. It's easy to use. It incurs no obligation. It makes sense. The Carborundum Company, Niagara Falls, New York.

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3 ***Classify and Segregate*** alloy steels and other special materials to be sure they are used to best advantage and to obtain higher prices.

4 ***Move Scrap Fast*** when it is ready. Sell it, ship it—keep it moving.

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To help you identify the common metals for proper scrap classification, we will be glad to send you, without charge, as many copies as you need of the wall charts "Identifying Metals by Spark Testing" (ask for form 4666) or "Simple Tests for Identifying Metals" (ask for form 2299).

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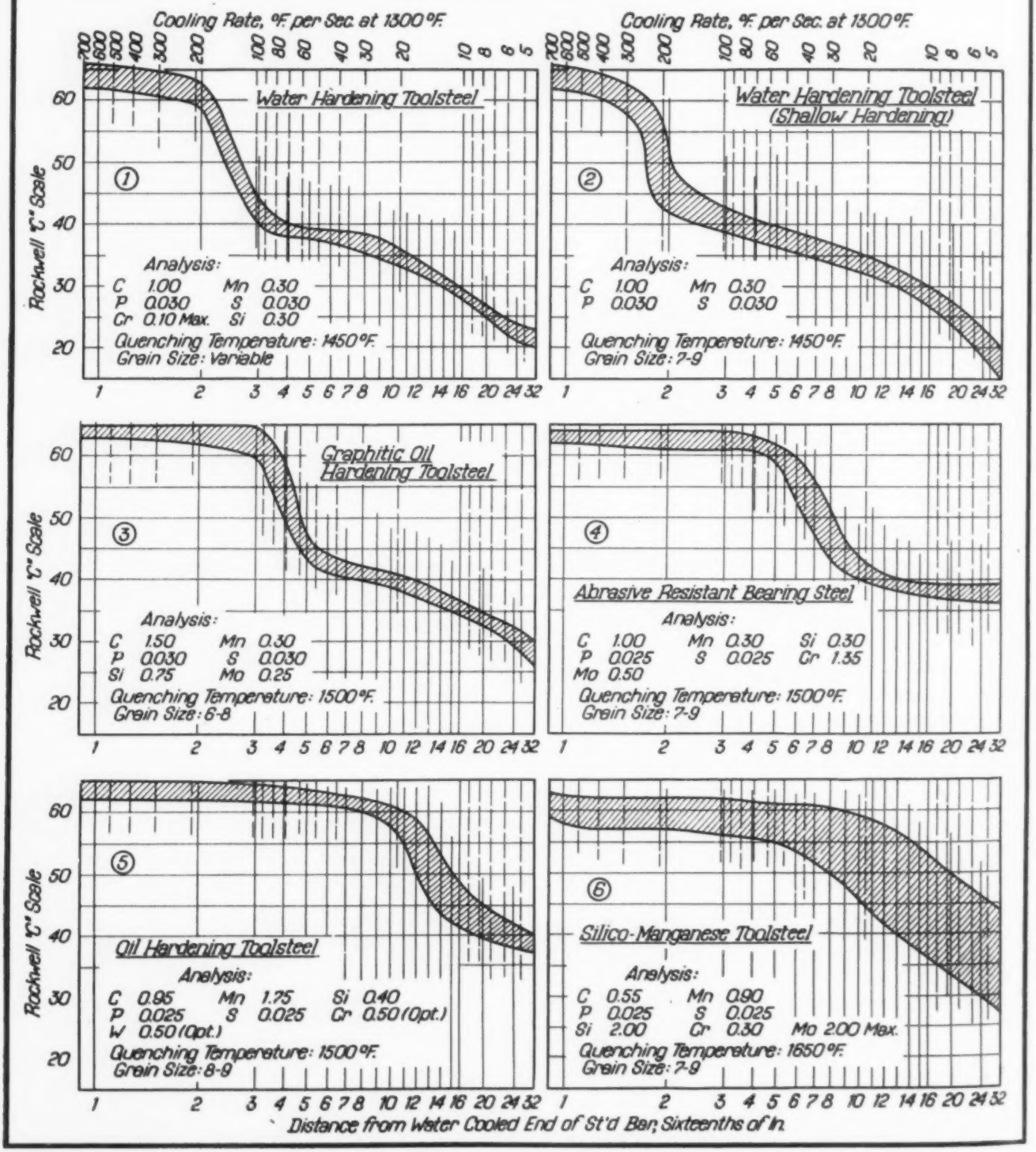
Hardenability of Common Toolsteels

Jominy End-Quench Tests by Stewart M. DePoy

Bands locate tests on numerous satisfactory toolsteels, in a variety of sizes all within normal analytical tolerances, made by Jominy's end-quench method as recommended by the Steel Standardization Group (see Data Sheet 55) except that the bars and test pieces were not normalized before testing. Plotting of the curves is done on the S.A.E. standard sheet, which plots distances logarithmically from the water-cooled end, thus opening up the horizontal scale usefully for the shallow hardening steels.



A group of papers organized
By Adolph Bregman
Consulting Engineer
New York City

Metal Cleaning Finishing Protection

Postwar Metal Finishing

By Adolph Bregman

FROM an economic standpoint the metal finishing industries flourished during the war. Contrary to the opinion of many, electroplating developed into an important factor in the war effort and the demands upon it were so great that the capacity of the industry had to be substantially increased.

After Japan surrendered, the situation changed completely. The industry swung back from the purely protective finishes demanded by the war to the decorative finishes demanded by civilian industry; high polishes reappeared in copperware, nickel, chromium, brass, silver and gold. Immediately, a shortage of skilled polishers was felt and at the present writing the industry is still suffering from this need.

Electroplating plants are now generally operating to the maximum of the capacity of available help and materials. If more skilled labor were available and materials were obtainable, more metal finishing could be done.

During the past year, formal Government restrictions on metals were eliminated except for chromium chemicals and tin, and O.P.A. maximum price regulation No. 581, which was issued March 31, 1945, was liberally amended as of July 25, 1946, and electroplating and metal finishing were decontrolled. Electroplating equipment is now freely purchasable. However, in actuality, most materials are harder to get now than before the Government restrictions were lifted! Silver has risen in price sharply and has been in very short supply. Chromium compounds, used widely in chromium plating, in chromate treatments for zinc, and as primers, have been critically scarce. Copper wire has been almost nonexistent due to long drawn out strikes in the wire mills and other branches of the copper industry. High grade zinc for anodes is very tight. The price of cadmium is up to $1.30 per lb., from 95¢, and it is hard to get. Tin supply is still far from catching up with the demand. Trichlorethylene and caustic soda cleaners are almost unobtainable.

Buffs and polishing wheels have been the most seriously affected of all materials, due to the lack of production of this type of cotton sheeting by the textile mills for industrial purposes.

An interesting development of the past year was the formation of the National Association of Metal Finishers, Inc., a nation-wide organization of job platers to consolidate and coordinate the various local organizations already existing in several of the largest centers.

In general, it may be said that the future of the industry from an economic standpoint is bright, providing labor and materials again become more freely available. In the meantime, we are suffering from the ills which afflict all American industry.

Technical Developments — Research is claiming more and more attention from the metal finishing industry. Below is a summary of the most important projects now underway, as well as brief notes on some commercial developments which have been described in recent literature.

A.S.T.M. Committee B-3 on corrosion of nonferrous metals and alloys has published a new tentative method of salt spray (fog) testing, designated as B17-44T.

Committee B-8 on electrodeposited metallic

coatings is conducting exposure tests of lead coatings on copper and steel; it is also considering changes in specifications for electrodeposited coatings of various kinds, especially nickel and chromium plates.

Committee D-12 has recommended standard methods for chemical analysis of industrial metal cleaning compositions.

A number of research projects have been undertaken by the American Electroplaters Society, including the following:

1. Stripping of copper.
2. Analytical methods.
3. Methods for testing adhesion.
4. The effect of surface finishing of nonferrous base metals in relation to the protective value of electroplated coatings.
5. The effect of impurities and their removal from plating solutions.
6. The nature and effect of porosity in electrodeposits.
7. The polarization at electrodes.
8. Physical properties of electrodeposits.

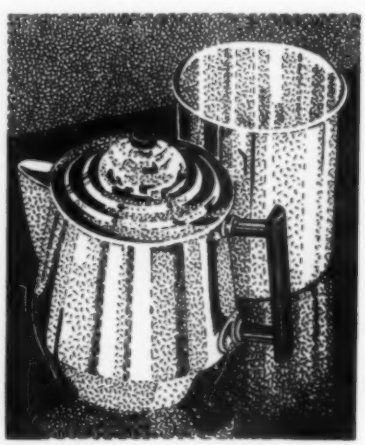
Supersonics have been utilized in applying a tin coating directly to aluminum in an interesting manner. Vibrations are applied to the aluminum sheet by supersonic waves as it is dipped into a molten tin bath. These vibrations knock off the oxide layer from the aluminum which is replaced immediately by a layer of tin which alloys with the aluminum surface.

Ordinary water can now be purified to the equivalent of distilled water by simple filtration through a synthetic resin. This process can be used, not only to provide pure water for plating operations, but also to extract impurities and precious metal values from plant wastes.

According to Wernick, a coating of tin under nickel, zinc, cadmium or other metals improves the distribution of the over-coating and also improves the service of the part so plated.

The electrodeposition of metal on plastics is making rapid and continuous headway, as can be seen from the contribution from Harold Narcus to this Section.

The electroplating of strip steel with tin is no longer news to the metallurgical industry. The critical need for this type of work will vanish once our free imports of virgin tin from Asia are resumed, but the method bids fair to remain with us, both in tin and zinc plating operations, because of the special properties these have over the hot dip coatings.



Indium assumed large industrial importance by its use in silver-plated bearings for aircraft engines during the war. There are doubtless many places where it will continue in permanent use during peacetime.

Chromate treatments for zinc, to reduce the formation of injurious corrosion products, have become standard practice.

An interesting development was a method of nickel plating on steel by chemical reduction as described by Brenner and Riddell of the National Bureau of Standards. An adherent, compact nickel coating can be deposited by immersion in a suitable bath on iron, nickel, gold, cobalt, palladium, and aluminum (but not on platinum, copper, zinc or lead). No appreciable precipitation of nickel occurs throughout the bulk of the solution or on the walls of the glass vessel. The solution consists of 30 g. per l. of nickel chloride, 10 g. per l. of sodium hypophosphite, from small amounts up to 100 g. per l. of ammonium chloride, from small amounts up to 100 g. per l. of sodium citrate; it is operated at about 200° F., and pH is 8 to 9.

Brenner and Olsen, also of the National Bureau of Standards, developed a method of purifying rhodium plating solutions which involves the precipitation of certain metallic impurities with potassium ferrocyanide.

X-ray diffraction examination of electrodeposits was described by Voyda, as well as its use in the study of problems in the production of electroplated parts for which no answers have been secured by other methods.

Electropolishing is another new branch of the metal finishing industry which is growing to substantial proportions. (See the contribution by Faust in this Section.)

Smith and Karle have examined electrocleaned steel by electron diffraction methods. This technique shows that a so-called clean metal surface is actually filmed with some chemical compound of the base metal (usually an oxide), or some compound of the elements in the cleaning solution. Adhesion of the electrodeposit apparently depends upon the thickness of the inter-surface film.

A periodic chart for electroplaters was set up by Dubpernell which appears useful for the correlation of information on the electrodeposition of metals.

Cutter described a process that has been developed for protecting magnesium from the

attack of chlorides or other corrosive environments by insulating the alloy from galvanic corrosion attack or by preventing the tendency to develop an electrolytic couple when brought in contact with a dissimilar metal. It also produces a slightly acidic nonmetallic surface which prevents the metal from developing alkalinity (thus insuring a good paint base).

A radically new development has taken place in polishing and buffing compounds, namely the use of sprayed compounds instead of the stick form. (See the contribution by Henry L. Kellner in this Section.)

A very useful improvement in metal finishing has been the use of the tumbling barrel for deburring. By these methods (sometimes called "finish honing") the parts are tumbled in sectional barrels with proper abrasives, and burrs removed in a fraction of the time formerly required and at a correspondingly reduced cost. It has been stated that precision-made parts such as gears may be finished in this fashion without altering required dimensions.

Industrial Standards

A useful advance in gold plating is involved in the newly proposed commercial standard for marking gold-plated articles. This has been developed by the Jewelers' Vigilance Committee, the New England Manufacturing Jewelers and Silversmiths' Association, and the National Bureau of Standards. This standard calls for a minimum deposit of 0.000,007 in. of gold on significant surfaces. This standard has been criticized by some important factors in the costume jewelry trade on the ground that it does not reflect the industry's practice, because a large volume of inexpensive gold plating is done in a range below this minimum figure.

An unusual development in nonmetallic finishing is strippable spray-type covering in which an impervious envelope is built around the part to be protected (regardless of its size) by a spraying operation. The scheme involves, first, cleaning the equipment or machinery to be protected, then festooning it with strips of tape connecting the outermost projections of the part to be packaged, then applying the spray which forms a coating in long web-like threads which provide a covering of interlocked and overlapping plastic threads, following the shape and contour of the object as modified by the strips of tape previously applied. As many coats as necessary may be used to provide a complete and continuous film or envelope, which is said to have a normal life of about five years.

Principles of Metal Cleaning

By Jay C. Harris
Monsanto Chemical Co., Dayton, Ohio

PERFORMANCE and speed were the prime criteria of adequacy applied to most processes during the war, and will become even more important requirements now. Metal cleaning is at best not an exact science, but attention to the fundamentals of cleaning will result not only in advancement of the art but in improved work and reduced costs. One definition of the cleaning process — which is admittedly an oversimplification — suggests that it is the application of force to a given surface in some medium to remove soil. (This definition applies as well to sandblasting as to pickling or soak degreasing.)

Machines which provide the necessary force or mechanical action for cleaning have soil removal as their primary function; secondarily, they place in their proper sequence the cleaning operation and the subsequent operations. Regardless of the type of machine involved, soil must be removed satisfactorily. This means that whether the *force* involved be jets of wash liquor, brushes or vapor, it must be adequate to remove adherent soil in the time allowed — and, as a corollary, the shorter the period the greater must be the force required. As always, there are degrees of cleanliness, and knowledge of the degree actually required for any succeeding step will mean economy of operation.

The press of war work taught us the need for proper usage of equipment, and hastened the combination of several types of cleaning operations to attain the job best suited to the processing which followed. With high labor costs these steps will now be the subject of closer examination and much more thought.

Cleaning Compositions — The fact that new machines and detergents are being developed means that improvement is anticipated by manufacturers of both machines and cleaning compositions. The trend in manufacture is toward items which will solve specific problems; the reason for this is apparent when the multiplicity of metals and alloys and their treatment (as well as their contaminants) is recognized. Introduction of new products and processes is a healthy sign, indicating active interest in the improvement of those now existing.

Producers of cleaning compositions are vitally interested in cleaning problems and have provided

much of the valuable data already published. In cases where details have not been published, proprietary or patented compositions have been specially designed for specific operations and a qualified staff of application men is often maintained to assist in solving cleaning problems — a matter of great value to the user of such a process.

Evaluation of Data — A view of the efforts being exerted in this field may assist in evaluating potential advances. One corporation with a multiplicity of cleaning problems has attempted to clarify its position by appointing committees, setting up specifications and (to advance their knowledge further) hold meetings of the responsible personnel, addressed by outside speakers well versed in their individual fields.

An active group working on the problem of metal cleaning is Section G of Committee D-12, American Society for Testing Materials, on Soaps and Other Detergents. The efforts of this group have been directed toward an evaluation of all available information with the ultimate object of furnishing methods and specifications for the industry. The interest in the field suggests that there may be much uncorrelated information available, and that once this has been catalogued, a more scientific approach to cleaning problems can be attained.

In addition to some few concerns in private industry, government agencies have set up many specifications which are directly or potentially useful in the metal cleaning field, and these form a useful backlog of information.

Although it is apparent that metal cleaning lacks much as a science, a groundwork has been laid, and it is hoped that advancement will now be rapid. In the meantime, the user may utilize pilot plant and actual plant trials (supplemented by available performance tests) to point the way. However, for best results and a clearer definition of required or practical cleanliness, the chemistry involved in subsequent processing must be defined in each specific case. To obtain optimum results, performance will remain the criterion of adequacy in metal cleaning.

Reel at End of Cleaning Line for Strip Steel
(Courtesy Hanson-Van Winkle-Munning Co.)

Postwar Metal Cleaning Methods

By Lionel De Waltoff
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ALTHOUGH World War II taught us more efficient ways of cleaning metals, these efficiencies were gained, for the most part, through improved design and better utilization of equipment rather than by radical changes in cleaner formulation.

There are many special ways of cleaning metals, such as shotblasting, acid cleaning prior to painting, molten baths for cleaning steel, and so on, but the following three methods can generally be used for almost any cleaning job, either alone or in various combinations:

1. Vapor solvent degreasing (usually used at the boiling point of such solvents as trichlorethylene or perchlorethylene).
2. Emulsifiable solvents (organic solvents plus emulsifying agents used either at room temperature or slightly above).
3. Aqueous alkaline cleaners (mixtures of various alkalies plus soaps, or wetting agents, used at elevated temperature).

Type 1 can be safely used for removing oils and greases from all metals and their alloys and is useful where aqueous solutions would be objectionable. For objects that are to be finished with organic coatings, no further cleaning is generally required. For objects to be electroplated or chemically treated it is necessary to follow a degreasing operation with an alkaline cleaning to insure good adhesion.

Type 2, like Type 1, can be safely used on all metals and their alloys, but has the further advantage of removing solid particles of dirt and water-soluble materials, such as soap and soluble oils, which Type 1 does not remove efficiently. This type of cleaner is most effective when used with good agitation, either mechanical or spray, and followed with a warm or hot water pressure rinse. If a chemically clean surface is required it is necessary to follow with an alkaline cleaner, preferably an electrocleaner.

Type 3 cleaners are the oldest and still the most widely used. They are as a rule compounded for specific requirements and are designed to give a definite pH range, depending upon the metals to be cleaned. Broadly speaking, these ranges are: pH 9 to 11 for cleaning metals such as aluminum, zinc, lead, tin and their alloys; pH 11 to 12.5 for copper alloys and other nonferrous alloys not mentioned above; pH 12.5 and above for ferrous metals and their alloys. The soak cleaners usually contain a larger amount of colloidal material to facilitate the removal of solid particles of dirt, and are normally used prior to a final electrocleaning where Type 1 or 2 has not been or cannot be used.

Electrocleaners differ from the soak cleaners by being more highly conductive and using special wetting agents which will not plate out at the electrodes as soap does.

Wartime Electroplating

By George B. Hogaboom
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TWO METALS that were not used in the electroplating industry during World War I became of most importance in the second war, namely, cadmium and chromium. The commercial development of cadmium for electroplating did not occur until about 1920; chromium plating was practically unknown until 1926.

The demand for cadmium, even at the beginning of the war now ended, was far greater than the amount of metal produced. Upon checking the specifications for cadmium plating by the Army, the Navy, and the Air Forces in the spring of 1942, it was found that eight times as much cadmium would be required as was available.

Chromium, that was generally used as an ornamental electroplated coating and (in a few instances) for building up defective parts for machinery, became an indispensable metal. Not only the metal and its ferroalloys were indispensable, but a salt, chromic acid, became equally important in the aircraft industry for anodizing.

Another metal, which the electroplating industry formerly considered purely ornamental, was silver; this also grew to prime war importance. It was a far cry from silver-plated tableware to silver-plated bearings for the motors of airplanes!

Indium, a "laboratory" metal, almost overnight became an integral part of airplane motor bearings — without which the long and successful flights would have been impossible.

Gold, so precious that many electroplated articles had a coating of 0.000,003 in. and often less, was essential as a protective and conductive coating for radar parts. Silver was used more extensively for the same purpose; the success of radar was to a considerable degree due to such electroplated coatings. Operations in the tropics, the far north, and the stratosphere — in fact in any place or climate — depended upon the quality of the gold and silver electrodeposits.

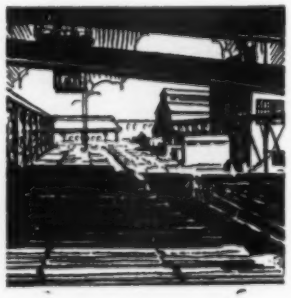
Lack of tin, tons and tons of which ended up in the nation's refuse dumps, threatened the food supply not only of the armed forces, but of civilian life all over the globe. The tin can became like the nail in the horseshoe; without it not only would the horse have been lost, but the war would have been lost. Hot tin dipping to obtain a coating of tin sufficient for canned goods was forced to give way to electrodeposition at speeds that were dreams come true — 1000 ft. of 36-in. steel strip per min.! And the triumph was made greater by the decrease in the consumption of "precious" tin from 2 lb. to as little as ¼ lb. per base box — 31,360 sq.in. of surface.

Zinc, which has always been considered the best electroplated coating for the protection of iron and steel against atmospheric rust, met its conqueror in the tropics. There it "rusted" itself; corroded so badly that parts like a simple snap fastener became so securely fastened that it was only with difficulty the parts could be pried apart. A salt of the metal unused during the first world war — chromium — came to the rescue and enabled zinc-electroplated parts — millions upon millions of them — to serve their purpose of protecting machinery, war equipment, shells and countless other parts from corrosion. The formation of zinc chromate on zinc surfaces reduced corrosion products to a point where they no longer interfered with the protective action.

In the early months of the war the stockpile of lead kept increasing until it reached enormous

proportions. Suddenly it was recalled that electrodeposited lead and an electrodeposited lead-tin alloy had been successfully employed during World War I. During the intervening years it had been almost forgotten. The shortage of zinc and cadmium for protective coatings forced the trial of lead, and though considered a lowly metal, it proved its value. Theoretical reasons why lead would not protect steel faded away before the actual performance in service. The huge stockpile kept diminishing and at the end of the war lead had become a critically scarce metal.

Due to the porosity of either hot dipped or electroplated lead coatings on steel, through which rust stains appeared, it was considered that lead offered no protection. Later it was found that the "rust" in the pores of the lead coating was insoluble; the pores indeed were filled with a product that gave better protection against corrosion than the lead itself! No wonder lead coatings were adopted and lead became an important substitute for zinc for lining containers for overseas shipment, and for protecting wire, strapping and telegraph and telephone pole hardware. On fence wire it not only gives good protection against corrosion but does not affect the physical properties of the steel core.



Porous Deposits — When electroplated coatings are specified, porosity is to be avoided. For nickel coatings on automotive parts not more than two pores of less than $\frac{1}{16}$-in. diameter per sq.ft. are allowable. Yet one of the most important developments during the war was the "porous chromium" deposit. When first proposed, there was considerable skepticism as to its workability and value. It was first applied to Diesel engine pistons where its success in extending their life was such that in a very short time all pistons and piston rings were so processed. The size of the piston, or diameter of the piston ring, or the quantity of either did not deter those who initially struggled against the opposition encountered — an opposition, strangely enough, not against the process but because the value of porous chromium coatings was not properly understood.

In this process chromium is deposited from a solution slightly modified from the one in general use for ornamental coatings. After the chromium is deposited to the required thickness, the electric current is merely reversed and the same solution then produces a peculiar porosity consisting of a thousand cavities of irregular shape. The edges of these cavities are later smoothed by a process called "honing".

Hard Deposits — In the production of machines and war equipment, imperfectly skilled labor often had to be used and it was inevitable that many parts that had to be machined to narrow tolerances were undersize. Electrodeposited chromium again became important in salvaging such parts by building up with "hard" chromium. By proper masking, chromium could be deposited on the defective portion only, after which the part was machined back to size. It often had a wearing surface harder and more resistant than the metal upon which it was deposited.

There were numerous parts wherein a hard surface was required at some special point. Instead of changing the tooling setup, this surface was etched by the newly developed "electrolytic polishing" method to a depth that permitted a hard chromium deposit of correct thickness to withstand wear in service.

Likewise, thousands of parts of all kinds of war equipment that became worn in service were salvaged by the electrodeposition of hard chromium. Electroplating plants were set up in each field repair depot to handle such work promptly.

Another application of this versatile metal chromium came about through the cafeterias which were set up for service men wherever possible. Mess trays were necessary. Aluminum was a critical metal and not available. Plastic trays were more or less attacked in hot dishwater, and were frowned upon because of the probability that they would harbor bacteria. Chromium on steel sheet, without an undercoat of scarce nickel, is not generally corrosion-proof.

It was found, however, that when the cold rolled steel, from which the six-compartment mess tray was made, was cyanide hardened and then — directly after quenching and passing through a mild alkali and some rinse water — was chromium plated at a high current density, a satisfactory mess tray was produced. The thickness of the chromium averaged 0.0003 in. Due to the treatment and thickness of the chromium, "hairline" cracks did not develop even after years of service. An obscure metallurgical question still exists: If gas or other methods of hardening the cold rolled steel were used, porosity resulted in the chromium coating, but cyanide hardening produced a surface over which the chromium deposits were free from porosity.

Silver and Gold — When several thousand ounces of silver are electroplated during a week's operation in any large tableware or silverware plant, no special comment is made, but when over

two tons of silver are deposited in the same length of time, it is news. That amount was required in one plant to electroplate the output of airplane and high-speed motor bearings. In another plant there is retained, as a souvenir, the millionth airplane bearing electroplated with silver. Through the ingenuity of the electroplater, equipment and plating solutions were developed by which silver was deposited at a rate far exceeding that previously thought possible, even on a laboratory scale. Smooth, dense and adherent deposits of silver were electroplated at the rate of 100 amp. per sq.ft. (Previously, 15 to 20 was considered high.) The steel was prepared in such a manner that bonding, silver to steel, was perfect, even when the bearing was heated to 1000° F.

It is still more news when it is known that in one large electroplating plant, several million ounces of gold were electroplated upon communication equipment parts during the war. One of the interesting developments was the bulk plating (in plating barrels) of plastic articles with gold. An example is the first service discharge buttons, which were made of plastic, gold plated.

Copper and Zinc — When shell cases were first made of steel it was thought necessary to plate the steel with copper for lubrication in the drawing dies. In many plants an immersion method was used, but later it was found that the shell could be drawn without a coating of copper.

Considerable copper was used in electroforming — a process of electroplating copper on some form usually made of a fusible alloy. An electroformed product of special interest was the "piezo tube". This intricate mechanism was cast in a fusible alloy of the shape required for the finished tube. The fusible metal was electroplated with copper to a substantial thickness, after which the alloy core was removed by applying a low heat. As each airplane was equipped with "piezo tubes", the number ran into many thousands.

The zinc-plated penny, over which there was so much unnecessary and uncomplimentary discussion, was the means of saving over 50,000 lb. of copper for far more important uses. One remarkable thing about the zinc-coated penny is that while the edges were bare, no rust appears on the bare part. (The coins were blanked from strip steel that had been previously electroplated with zinc and no subsequent plating was necessary to protect the zinc-free or bare edge.)

As previously stated, it is not possible to tell the whole or even a large part of the story of the electroplating of war equipment and material; its value has been demonstrated beyond any question. Much has been learned that has carried over into peacetimes; the end of progress is far, far off.

Plating on Plastics

By Harold Narcus
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MAINLY because of their extensive use in wartime industrial activities, the applications of various methods for plating on plastics have increased greatly in the postwar period. Several plastics, which have become established on their own merits, are now being coated with suitable metals, the result being a combination of all the inherent properties and advantages of metallic and nonmetallic substances. This unique combination of a nonconductor and a conductor promises to be widely used in future radio, television and electronic activities. The costume and novelty jewelry industries have also utilized these metallizing processes with excellent results.

The undesirable properties of many plastics, such as absorption of oils, solvents and moisture, which may cause them to swell or distort, are eliminated by the proper choice and thickness of the outer layer of metal. The weatherability of the plastic is also greatly increased. Experiments by the present author, described last year before a meeting of the Electrochemical Society, show a marked increase in tensile, impact and flexural strength for many plated products made of synthetic resins, as compared with values for the same resins unplated. An appreciable increase in resistance to distortion from heat and a decrease in the percentage of water absorption are obtained by complete envelopment of the plastic in a suitable metallic coating. However, the advantage is not all one-way; another most important advantage of plating on plastics is the greater corrosion resistance of a metallic deposit when it is applied to a plastic basis material than when applied to the usual metallic basis material, since no galvanic couples are formed with a plastic, as there are with a basis metal.

The uses of metallized plastics are evident, therefore, when the foregoing is analyzed. They are widely employed as screens against magnetic fields, high frequency currents or radium emanations in electrical and electronics engineering. The substitution of one component for two or more others is possible, since the plated plastic will retain its general nonconductive properties, yet

the conductivity of the surface can, if desired, be utilized. Commutation is facilitated through selective electroplating in depressed grooves of a molded plastic piece. Costly inserts and assembly operations are eliminated in a similar manner in electric shielding of aircraft instruments and radio shielding devices, giving a product which is lighter and more quickly fabricated.

The process of plating on plastics, while not intended merely to imitate metal, yields a product which cannot be economically made in metal. The intricacy of certain metal shapes is no longer a problem.

Soldering one metallized plastic component to another or to a metallic unit is now practicable.

Contrary to the beliefs of some, the cost of plating plastics, while somewhat higher than conventional plating on metal, is low in comparison with the final cost of the plated plastic part and, in many items, of a similar part made entirely of metal and electroplated with the same electrodeposit.

The methods for rendering the plastic material conductive for subsequent electrodeposition with the desired metals has been described in the literature rather fully. See, especially, an article by S. Wein in *Metal Finishing*, 1944, page 669. Patents have been granted for the majority of these methods, and this patent information is also readily available. The most successful method is the so-called chemical reduction method. Basically, it consists of the chemical reduction, on the properly prepared plastic surface, of a highly conductive and reasonably adherent silver film, employing an ammoniacal silver nitrate solution with a suitable reducing agent, followed by an intermediate layer of electrodeposited copper and a final layer of the desired outer metal.

Electropolishing in Postwar Finishing

By Charles L. Faust
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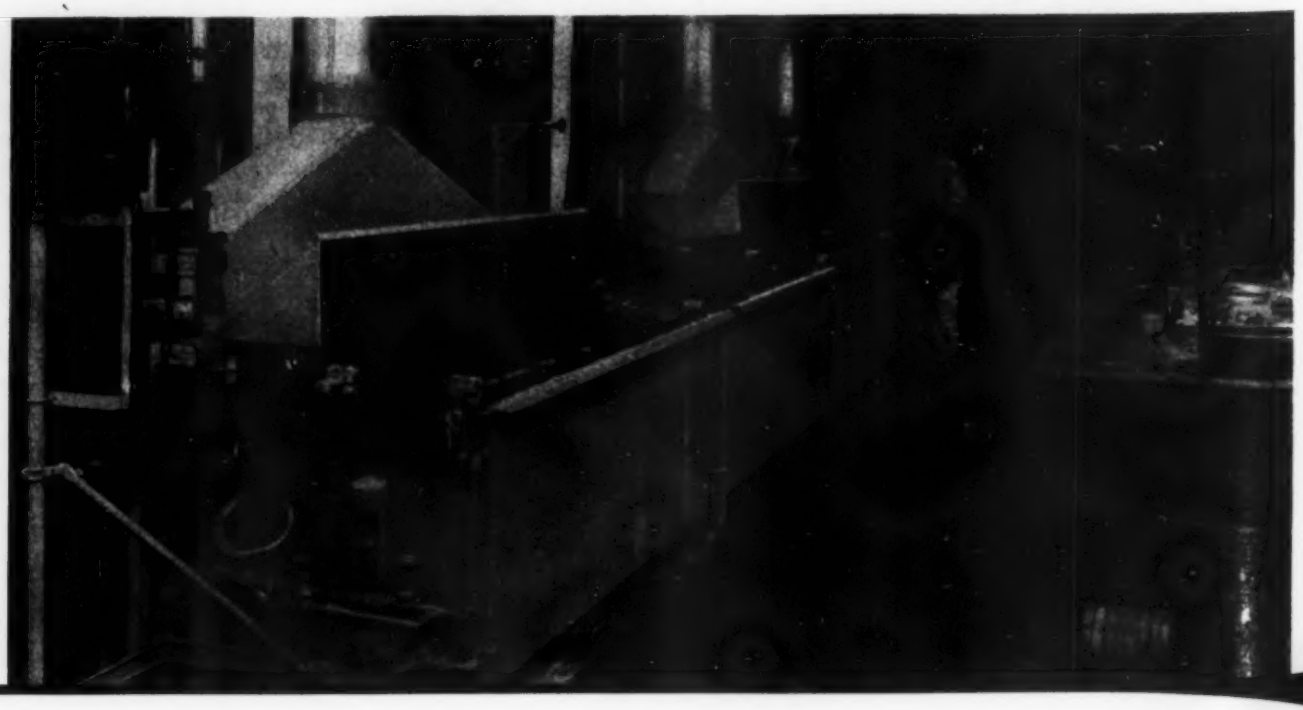
INDUSTRIAL interest in electropolishing is expanding at a rapid rate, and the process is assuming an important place in postwar metal finishing. Reconversion problems and shortages in materials, equipment, and lack of good polishers and buffers are leading to many opportunities for the new process. It is an electrolytic process for surfacing, machining, or finishing metals. The work is made the anode in an aqueous solution; the equipment has the outward appearance of an electroplating unit. Brilliant color, having an exceptionally attractive tone, is produced without cold working effects, heat effects, and attendant distortions that accompany mechanical surfacing methods. The finishing is accomplished by dissolution of a thin layer of surface metal to produce microsmoothness and some macrosmoothening. The action takes place under highly polarized or pseudopassive conditions which do not prevail in simple electrolytic cleaning treatments. Thus, being electrolytic, the process is dependent on original surface condition, on the physical and mechanical nature of the part, and on the inherent cleanliness of the metal. Seams, nonmetallic inclusions, deep rolling or drawing lines, orange peel, pickle pits, and certain insoluble phases are uncovered and they may or may not be removed.

Bullard-Dunn Electrocleaning Unit (Manual Operation) at Pratt & Whitney's Plant



Electropolishing does not provide the cutting and burnishing action of wheels and tumbling barrels. Hence, it can never reproduce the appearance of a mechanically polished, buffed, and colored surface. One must immediately recognize and accept the fact that there is no "electrolytic wheel finish". Because of its action to color without burnishing, electropolishing produces a *new* surface finish. Irregularities become apparent in relatively flat surfaces, but less so, if at all, in contoured surfaces or in those broken by design.

Excellent luster is produced on surfaces too rough for practical polishing by other methods. If electropolishing is to produce, commercially, good color *plus* smoothness, surface irregularities should not exceed the magnitude of a 180-grit scratch. However, satin tone to brilliant sparkle is produced in attractive appearance on rough surfaces. A uniform texture, hiding surface irregularities and metal defects, is produced by sandblasting or shotblasting before electropolishing.

The foregoing fundamental facts must be recognized whenever electropolishing applications are under consideration. When the proper approach is made with an open mind on "what is acceptable as a polished finish", technical and economical advantages are found for commercial electropolishing operations.

Numerous companies are now using the process in production, or in pilot-plant appraisal of the economics where the results are technically acceptable. Many additional companies are interested in the practical possibilities, but are held up by materials, labor, and equipment shortages.

The process is applied with practical advantage to wrought, cast, and electrodeposited metals, as pointed out by the present author in a paper in *Proceedings* of American Electroplaters' Society for June 1946.

No outstanding postwar improvements have yet been made in the methods that were commercial when the war began.

Electropolishing is done at higher current densities and tank voltages than electroplating. Equipment can be automatic, semiautomatic, or hand operated. Barrel electropolishing has also been done successfully on some parts. However, there is need for improved methods. Electropolishing tanks require no unusual materials, being lined with lead, glass, or synthetic rubbers or resins. The equipment investment is about the same as for electroplating, and operating costs are only slightly higher.

Electropolishing can only be accomplished *by removing metal,* which operation consumes chemicals. Costs are based on direct charges similar to those for plating and may be either cheaper or more expensive than other finishing methods. Each use must be adapted by tailor-made application, which considers the whole manufacturing schedule of a given article. Therefore, the cost cannot be expressed by a single, general figure, any more than one figure can be given as to the cost of making a pound of steel. Costs will range from extremes — 0.5 to 25¢ per sq.ft. of surface processed. The "sq.ft." may be for one part, a portion of a part, or for a large number of small parts. The cost depends on the kind of metal or alloy, its original surface condition, and the kind of bath being used.

Practical methods are available for the most generally used stainless steels, low alloy and carbon steels, red brasses, aluminum and its alloys, copper, nickel, monel, nickel-silver, nickel-chromium alloys, silver, magnesium, and zinc.

Best results are obtained with clean homogeneous alloys. Zinc die castings and many of the aluminum die castings, due to their microstructure, still defy commercial electropolishing to brilliant luster. Leaded brasses and aluminum alloys containing silicon are electropolished by methods having limited practicability.

Many types of solutions are usable (see Zmeskal's list in *Metal Progress,* for April 1945, page 729). The most economical and technically satisfactory methods are patented, but reasonable licenses for use are generally available. Practically, the methods of broadest application are based on sulphuric and phosphoric acids.

Sulphuric-citric and phosphoric acid solutions are in plant use on stainless steel. Stainless steels, carbon steels, nickel, nickel-silver, aluminum, brass, copper, and magnesium are being electropolished in sulphuric-phosphoric, sulphuric-phosphoric-chromic, or phosphoric-chromic acid.

Commercial tank sizes range from 100 to 4000 gallons; currents are up to 90,000 amp. per installation at supply voltages of 12 to 18 volts. Practical current densities range from 100 to 500 amp. per sq.ft., and, in special cases, from 750 to 1000. Articles being electropolished are of sizes ranging from surface areas of 0.001 sq.ft. to over 2 sq.ft.

Commercial application is to costume jewelry, electric appliances, automotive and architectural trim, name plates, novelties, small tools, electronic parts, wire products, kitchenware, plumbing fixtures and watch parts.

Electropolishing opens new avenues in design and appearance and effects new economies in manufacturing methods. Particularly intriguing effects are attainable by shotblasting, with or without two-tone effects, and then electropolishing to make the article slick to the touch and provide color tone ranging from satin to brilliant sparkle.

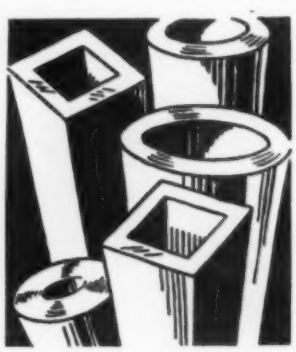
Polishing and Buffing

By Henry L. Kellner
Technical Director
The Lea Mfg. Co., Waterbury, Conn.

MANUFACTURERS, whose production in some degree depends on buffing and polishing, are constantly seeking improved methods that have either grown out of techniques developed especially for war work, or postwar developments that have been completed since laboratory men have returned to unfinished projects, unhampered by defense considerations.

During war production, little thought was given to the development of better methods for producing bright finishes, since they had practically no part in the armament picture. Polishing (the preliminary coarser cutting operation) was, on the contrary, a required procedure for innumerable parts. Polishing, for removing coarse imperfections and burrs, was not an intermediate operation but an end in itself.

For such work a flexible polishing technique was developed which had many advantages over the conventional polishing wheels formerly used predominately. With parts having irregular contours, flexible polishing wheels providing a dry, resilient abrading head were found ideal for breaking edges and removing burrs where the conventional unyielding polishing wheel could not reach into and touch the required portions without at the same time destroying critical size tolerances.



The cutting face of a flexible polishing wheel is formed and maintained by periodic frictional transfer of greaseless compound in bar form to the revolving wheel. By selecting a wheel of proper resiliency the desired degree of flexibility is obtained. For example, packed full disk muslin buffs, or string wheels, would be found on the "soft" side, going to compressed canvas wheels or sewed buffs on the "hard" side. These wheels will run at speeds from 4000 to 6000 surface ft. per min. when used in flexible polishing.

Although flexible polishing was originally developed for ordnance and aircraft parts, operators of reconverted war plants have already found innumerable items in civilian goods that lend themselves to this labor saving procedure. Because of the ease by which flexible polishing wheels follow contours they are replacing conventional polishing wheels in the finer numbers every day. In civilian production the flexible polishing operation is generally preliminary to buffing, plating or lacquering.

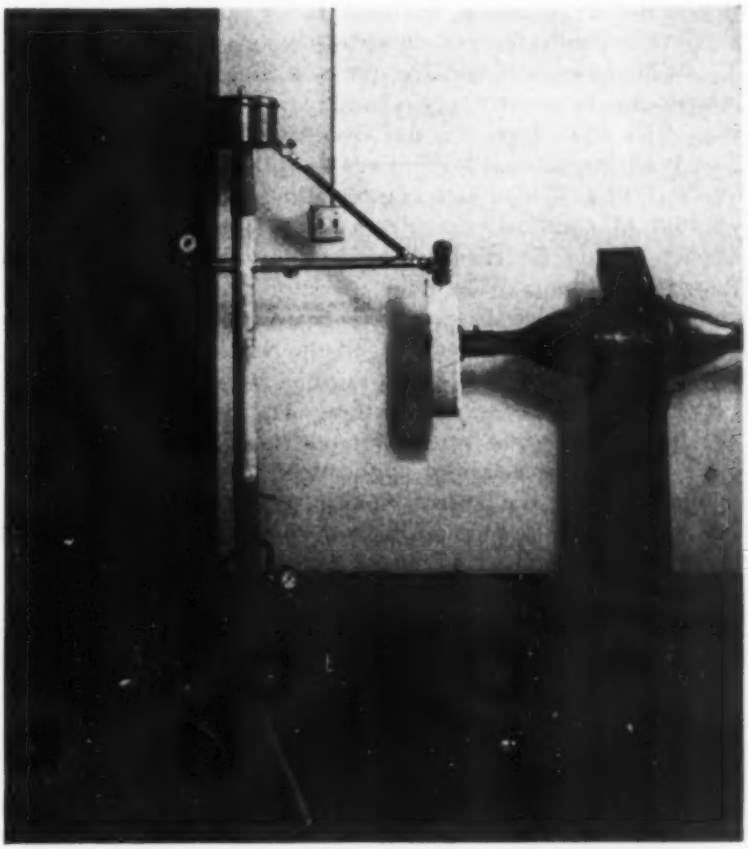
Some armament parts were of such nature that they could not be burred by the procedure mentioned. This led to a further development in polishing, stemming directly from the underlying principles of flexible polishing. Often the edges of the parts were such that they would tear the wheel excessively; something was required to provide a more rugged cutting face. It was known that the conventional rag polishing wheel, when well broken in, would do such jobs efficiently, but too much time was lost in bringing the polishing wheel to the proper broken-in condition. Eventually a sizing coat in bar form, similar to greaseless compound but without the abrasive, was developed to serve as an undercoat for a sewed polishing wheel prior to the application of greaseless compound. In addition, the following variation in technique of applying both the sizing coat and the greaseless compound was found necessary for best results:

The bar of sizing material is brought to the revolving wheel, pressure is applied and the power is shut off. This allows a heavy sizing coat to melt and flow onto the surface of the wheel. The lathe is then turned on and off to initiate drying at less than full speed, and then run at full speed until the sizing coat is not sticky to the touch. The total drying time is approximately 2 min. The same procedure is followed with the bar of greaseless compound — pressure again being applied as the power is shut off. Drying procedure and its duration were about the same for the greaseless compound application as they were for the sizing coat. It is essential that this start-and-stop technique be followed closely, for if the sizing material or the greaseless compound were applied with pressure at full speed, most of the material removed from the bar would be thrown off the wheel, whereas with deceleration these materials are flowed satisfactorily over the surface.

A polishing head $\frac{3}{16}$ in. thick can be prepared by this method although it is generally necessary to make a second application of greaseless composition for the heavier heads. Although restricted to grit sizes of No. 80 and finer, such wheels are true polishing wheels that never need to leave the lathe, and the polishing head can be formed in 7 min.

Conventional polishing wheels are still useful and necessary tools in the finishing of metals, particularly where considerable metal must be abraded away to get a proper "bottom" for the ultimate finish desired. In the finishing field the greatest change is due to postwar shortages. Polishing wheel glue, for years the stand-by of the oldtime polisher, is exceptionally scarce because of the shortage in animal hides. Many polishing wheel cements are today being tried as substitutes by many polishers who formerly resisted any change in their established procedure; cements are being given a chance to demonstrate their own particular merits for setting up polishing wheels, which will undoubtedly result in a permanent place in polishing operations even after shortages no longer exist.

Speaking of shortages in the buffing and polishing field, we cannot fail to make some mention of the present scarcity of muslin buffs. The time has long passed since a consumer of buffing wheels bothered to specify the exact cloth he required for his various polishing and buffing operations. Today muslin buffs are muslin buffs regardless of the weave, and the individual buffer cannot be too highly praised for turning out high quality finishes with the inappropriate mediums he has had to use. His ability to turn out acceptable merchandise with buffing wheels that may be made from curtains, tents and lingerie remnants is reason enough to pay tribute to the ingenuity of the American worker.



Demonstration Unit of Spray Equipment for Buffing Composition, Moved in Place to Serve a Conventional Buffing Lathe

Undoubtedly the biggest single development in the buffing field is a group of advances in spray equipment, together with variations and improvements in liquid polishes, resulting in a production method for spraying buffing compositions onto the buffing wheel. As the most immediate need for such buffing is in the finishing of nonferrous metals, Tripoli compositions were the first to be developed and, as a class, these liquid compositions are often referred to as "Spray Tripoli". This procedure was brought forth many years ago, but spray equipment was not good enough. Although the war effort was not directly responsible for the development of the proper spray composition technique, it did foster improvement in spray equipment in general, which in turn led to the production of airbrush devices which meet all the requirements of spray compositions.

"Spray Tripoli" consists of the standard Tripoli abrasive powder suspended in a grease or oil-base binder which is liquid at room temperatures. Thus it is contrasted to the usual solid bar Tripoli. The fluid spray composition is fed through hose, either by gravity or pressure, to a spray gun or airbrush of proper design, mounted above the buffing wheel in such a position that it will not interfere with the operator in manual buffing operations, or with other parts of the mechanism when attached to automatic machines. This liquid composition is sprayed, by air pressure, onto the buffing wheel at predetermined intervals as the composition is required. For manual operations, this is done by a foot valve, which allows the operator to have both hands free at all times to handle the work being finished.

Thus, there is no need for the operator to stop buffing, as when applying a cake of conventional solid composition; at the same time he is not required to put in any noticeable extra effort. He is merely using all his time in production rather than part of it in preparing for production.

Equipment of this sort could easily be built into the pedestals of buffing lathes, and be entirely self-contained, or be serviced by compressed air from the general shop pipe lines. The accompany-

ing half-tone shows a portable spray unit with small electric-driven air compressor.

With automatic buffing machines there is, of course, not this additional advantage of labor saving. The advantages for automatic buffing which also hold for manual buffing are as follows:

1. The buff is always coated with the optimum amount of composition. From this standpoint, supply should be regarded as continuous rather than intermittent. When the operator uses a bar composition, there is generally a considerable excess of buffing composition on the wheel immediately after the first application, and a deficiency just before the second application. The first parts are buffed with too much composition, and the ones just before a second application do not have enough. With the spray method, each piece is buffed with the desired amount of composition.

2. When buffing is done with either an excess or deficiency of composition, the buff is worn unnecessarily. With spray compositions, excessive buff wear is eliminated.

3. Excessive amounts of bar composition applied to the wheel generally pack solid buffing dirt in the crevices of the article being finished. This has always presented a serious cleaning problem after conventional buffing. As excess composition is never present with the spray method, residual dirt of properly formulated compositions is easily cleaned.

4. Conservative estimates show that only 50% or even less of spray composition will be used than of conventional bar compositions for the same amount of work buffed. In addition, there are no butt ends or nubbins of buffing composition left over, which cannot be efficiently reclaimed.

5. With conventional buffing, muslin buffing wheels have often caught fire when high pressures are used and a deficiency of composition existed. This is eliminated by the spray composition technique which insures that sufficient composition is always present. This is true, however, only if a spray composition is selected which in itself does not constitute a fire hazard by being formulated with combustible fluids.

Although "Spray Tripoli" has received more attention than other types of liquid compositions, and has undoubtedly reached the greatest state of development, other spray compositions employing abrasive powders for buffing and coloring steel, stainless steel, plated surfaces, and various alloys have been developed, and will be found in production buffing operations in the very near future. With the advantages of spray compositions so numerous, it is conceivable that this technique will shortly become the standard procedure for production buffing in virtually all metal fabrication.

Recent Publications on the Testing of Metallic Finishes

By Myron B. Diggin
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and Otto Kardos
Research Chemist
Hanson-Van Winkle-Munning Co.
Matawan, N. J.

DURING the war years American industry became increasingly specification-conscious. This trend will certainly continue as competition increases and as the consuming public expects more serviceable finishes. Such an advance will parallel a better understanding of the factors involved in the production and evaluation of electrodeposited coatings, and this in turn will result from the various research projects now being conducted by the American Electroplaters' Society, such as Project No. 3 on "The Adhesion of Electrodeposits", Project No. 6 on "The Nature and Effect of Porosity in Electrodeposits", Project No. 7 on "Methods for Testing Thickness of Electrodeposits" and Project No. 9 on "Physical Properties of Electrodeposited Metals". Thus far a series of informative reports[1] have been published on Research Project No. 3 (Project Director, A. L. Ferguson) comprising a bibliography, general considerations, correlated abstracts of published methods for measuring the degree of adhesion of electrodeposits, and critical comments on such methods.*

Thickness of Electrodeposits — Edward Engel[2] gave a table on the procedures for testing thickness of the various metal deposits. S. Lipson[3] and E. S. Spencer-Timms[4] described new magnetic thickness testers.

H. W. Parker[5] developed a test for local thickness of zinc coatings wherein a test tube, with the closed end cut off, is sealed with beeswax to the zinc area to be tested. The thickness of the coating can be calculated from the volume of a solution of hydrochloric acid and antimony trichloride which is necessary to dissolve the zinc coating in the selected area.

S. G. Clarke[6] also devised an end-point indicator for the B.N.F. jet test for zinc coatings (also applicable to the Hull-Strausser drop test). One or two drops of this indicator (an aqueous solution

*Superscripts refer to literature references, at end of article (pages 1078 and 1080).

of 200 g. per l. of potassium ferricyanide and 200 ml. of 1:1 hydrochloric acid), when applied to the tested spot, indicates whether or not perforation to the base metal has occurred. E. S. Spencer-Timms[7] also reported on the spot test for the thickness of chromium coatings on nickel using hydrochloric acid. The results agree with those published earlier by Blum and Olson.

L. S. Birke and W. Friedman[8] measured coating thickness by X-ray absorption.

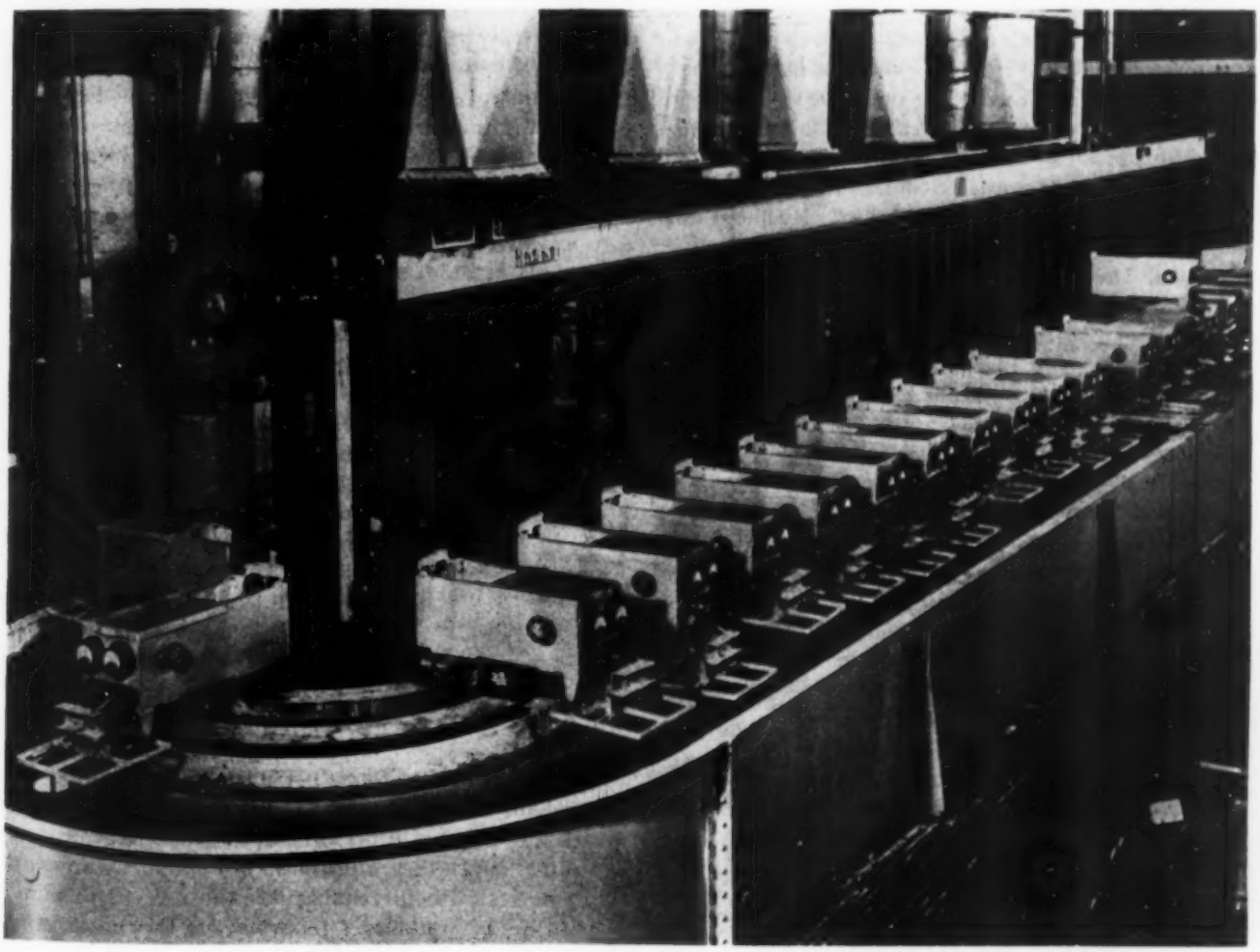
Porosity and Continuity of Electrodeposits — H. D. Hughes[9] described electrographic methods for the identification of electrodeposits, methods which should be partially applicable to testing for porosity. The method was derived from the old scheme of locating sulphides in steel by placing a photographic paper in close contact and moistening with weak acid. C. H. Aneshansley[10] also described an electrographic test for the continuity of chromium flash deposits on steel.

E. Engel's previously noted paper[2] presented a table on porosity tests for various combinations of electrodeposits and base metals.

Adhesion — The outstanding contribution on adhesion is the already mentioned report[1] on Research Project No. 3 of the American Electroplaters' Society. Based on the material assembled in this report, experiments are in progress for the further development of simplified, quantitative and nondestructive adhesion tests.

Some other recent publications are worthy of consultation: Charles L. Faust[11] proved the necessity of distinguishing between *bond strength* (measured by the force required to separate the plate from the base metal regardless of the place of fracture) and *adhesive strength* (measured by the force required to separate the plate at the interface between itself and base metal).

A. W. Hothersall and C. J. Leadbeater[12] described and discussed the B.N.F. (vibrating ball-ended hammer) adhesion test, the shot impingement test and the electrolytic adhesion test (appli-



Fully Automatic Plating Installation, With Control Instruments on Each Work Carrier, and Exhaust Risers Going Up Through Center of Framework. (Hanson-Van Winkle-Munning Co.)

cable only to coatings permeable to hydrogen). In all these tests the deposit is made to expand, generally or locally, and the coating blisters or flakes off. Burr Price[13] also described the conical mandrel test and the scratch adhesion test.

Abrasion — In that same article Burr Price described an air blast apparatus for measuring the abrasion resistance of oxide coatings on aluminum. G. B. Hogaboom[14] compared the wearing qualities of gold deposits and good lacquers, as measured with the Taber Abraser.

Corrosion Resistance — H. P. Troendly[15] published a manual of operations for salt spray testing, and details of the equipment as developed by cooperation of the U. S. Ordnance Department, the Borg-Warner Corp., Parker Rust-Proof Co. and Industrial Filter and Pump Mfg. Co. This manual is based on the general recommendations of A.S.T.M. Specification B117-44T. One of the many factors which are important for reproducible results is the measurement and control of the salt fog by two collecting devices.

R. M. Burns[16], in a valuable discussion, reviewed and evaluated various laboratory corrosion tests, such as by immersion, humidity cabinet, salt spray, and by measuring potentials. He cited a present trend in exposure tests to the use of natural atmospheres, highly humidified at elevated temperatures with condensation induced by cyclic temperature or humidity regulation. He mentions temperature or humidity regulation, and the necessity of correlations between salt spray tests and service results.

The salt spray has come in for a lot of critical comment. G. T. Dunkley[17] discussed its applications, whereas G. B. Hogaboom[18] demonstrated the importance of testing stripped electrodeposits (instead of the plated articles) in the salt fog cabinet. Certain stripped deposits of bright nickel developed numerous perforations in the salt fog test which he ascribed to solution of co-deposited colloidal substances. C. F. Nixon[19] proposed a salt spray test modified with acetic acid (20% NaCl, 1% glacial acetic acid, pH 3.2) for testing plated zinc-base die castings. His data indicate that this modified test gives better agreement with outdoor exposure tests than the usual salt fog test. The indicator of failure is the development of blisters.

C. F. Kettering[20] reported on outdoor exposure tests of plated and painted panels. Of two sets of panels, the one exposed outdoors from 6 p.m. to 6 a.m. failed in one-quarter of the time required for the set exposed from 6 a.m. to 6 p.m. To investigate the cause of this different corrosion rate, three rows of panels were exposed, one of them kept warm by incandescent lamps behind the plates, another row cooled by small refrigerating coils and the third exposed under normal conditions. With the aid of a dew meter (a wick held down on the plates which, when damp, conducts an electric current which is measured by an accumulating clock) it was found that the rate of failure was proportional to the total hours of dew formation, corrosion rate being highest on the cooled panels, lowest on the heated panels. C. H. Sample[21] also discussed briefly the methods of rating electroplated test panels in outdoor exposure and concluded that a rating directly in percentage of surface discolored is of most value to industry.

E. Engel[2] listed comparative corrosion data on various electrodeposits. Several authors[22] have reported on the tests conducted at the Kure Beach Test Station, near Wilmington, N. C., where about 19,000 specimens, some of them electroplated, are exposed to sea water and marine atmosphere.

Control of Alloy Electrodeposits — H. E. Zentler Gordon and Eric R. Roberts[23] reported on routine control methods (polarographic, electrolytic, volumetric) for brass deposits and plating baths. Rapid methods of analysis are evidently of greatest importance, else the bath may produce much unsatisfactory material while the necessity for adjustment is still under investigation. In order to insure perfect adhesion of rubber to alloy they stated that the deposits should contain from 72 to 78% copper and be free from co-deposits of certain ammonia-ferrocyanide complexes (identified by X-ray diffraction). Th. Voyda[24] also used the same methods to examine the composition and structure of alloy deposits and diffusion coatings such as lead-tin and copper-tin.

Various Methods of Control — C. W. Smith and I. L. Karle[25] measured by electron diffraction the thickness of the invariably present surface films on electrocleaned steel, and found that the adhesion of electrodeposits decreases with increasing thickness of these films.

W. L. Maucher[26] reported on the breakdown voltage of anodized aluminum alloys, and Edward Engel[27] surveyed the application of various instruments and methods for testing metal surfaces.

Posiwar Paints and Painting Methods

By E. A. Zahn
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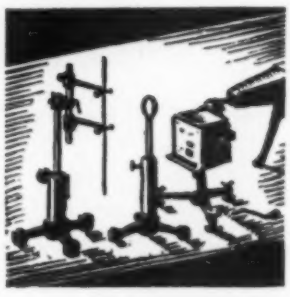
THE CHIEF PROBLEM facing industrial users of paint at the present time is the shortage of good paint materials, rather than problems of new paint developments. The industrial consumer's laboratory as well as his cost, production, and purchasing departments are busy securing and testing available materials in an effort to maintain a high standard of quality in the face of the scarcity of such basic items as titanium, oils, and resins.

When normal conditions of supply do return, however, it is safe to say that many of the old materials will not stand much chance against some of the newly developed, but still too critical, radically different types. Some of these new items are as yet little known even in the industry.

One of the new developments which promises to revolutionize many present procedures is the non-oxidizing, 60-sec. curing, high temperature synthetic enamels. They have possibilities of curing in production beyond anything previously known to the trade. It requires real imagination to think of a paint material that takes less time to cure than it takes to apply it! One of these types (which will soon be available in all colors, including pastels and clears for polished metal) can be cured in 60 sec. at temperatures of from 400 to 500° F. It will be possible to expose fairly heavy metal parts to an atmosphere of 500° F. or more for such a short cycle that the metal mass need not be entirely heated. It may even be possible to cure these materials in an exposed flame area which would consume solvents, since the materials will not depend on an oxidizing atmosphere. These short cycles and high temperatures will not discolor white and clear coatings nor make it more difficult to cure them over polished metal reflecting surfaces.

New developments in automatic painters have outclassed everything previously used. Automatic painting machinery is being built which, for the first time, can handle a variety of parts simultaneously. This machine includes several stages of automatic cleaning and chemical surface treatment. It applies paint at a rate faster than ever before, and is equipped with curing facilities requiring no labor other than loading and unloading a specially designed conveyer. However, the very new feature of this machine is its ability to handle a variety of parts which may range in size from 2 in. to 2 ft. or more, and in weight from a few ounces to more than 100 lb. Even more important than the variety of weight and size is the equipment's ability to handle an object of any shape. The estimated utilization factor is at least equal to the dipping method, which up to now has been the most economical. This machine will be geared to handle dozens of small parts per minute; smaller quantities as sizes diminish.



Other new developments include synthetics which dry equally as fast as lacquers — and in some instances faster. This particular type of finish, like many others, was under consideration before the war but lay dormant. It is not unusual for this type of material to act as both priming coat and finish, in one or multiple-coat application. It may be baked, if desired, and will accept lacquers in either air dried or baked form.

A great deal has been said concerning the precoating of metals at the steel mill. Special coatings have already been developed which can be cured by utilizing the heat of steel processing operations. In one type, arc welding spatter resistance as well as arc weld stabilization are proven features. This sheet steel will withstand several months' storage weathering and thereby avoid expensive cleaning before fabrication by welding. The coating remains after welding as an excellent undercoat for future finishing — with the exception, of course, of the area where the weld is made.

Another precoating type of material has been developed that has features which promote resistance welding fabrication, especially spot welded designs, since it provides protection between overlapped edges which heretofore had been a common area of corrosion.

All of these new developments (and more which will obviously come later) have an additional value to the industrial paint user. With each new product developed come additional possibilities for the engineers of both producer and user to come together on common ground. These developments also rule out the old-fashioned, high pressure selling methods, along with guesswork in testing. The entire processes of painting, paint development and testing will of course not be suddenly changed, but there is certainly every right to feel that the immediate future will provide better quality in industrial painted products.

Postwar Organic Finishes

By Gustave Klinkenstein
Vice President
Maas and Waldstein Co.
Newark, N. J.

AS IN ALL OTHER materials, the war caused considerable changes in organic finishes for metals, and the end of the war witnessed a sharp reversion. The immediate swing from war to civilian production put substantial strains on the industry, as the engine was reversed while going at high speed. Consequently, we are not yet out of the so-called reconversion period, and we are still far from being in smooth running order.

As regards availability, almost all of the materials used in organic finishes are now free from Government restrictions and controls. Theoretically, therefore, all of the new materials and combinations developed for war purposes are now available. Actually, however, this is far from being true. Severe shortages are due to dislocations of our sources of supply, greatly increased exports and the unprecedented demand.

The actual quantity of raw materials available to civilian industry is huge and growing steadily. New facilities are coming in which were planned during the war. But the pent-up demand for special finishes is so great that frequently production cannot keep up with it.

Another and unforeseen complication is the derangement of the world-wide food supply. There is a great demand for edible fats and oils that can be used in finishes and which enter into the manufacture of resins. Linseed oil, an important constituent, is an important food in certain areas in Europe. These overpowering demands have resulted in even greater shortages than the general industrial situation would be responsible for.

A few formulations developed especially for ordnance and stores will be broadly applicable to postwar civilian uses — either as such or in modified forms. Among these are the following:

1. Fungus resistant lacquers, varnishes, enamels, and paints for tropical conditions.
2. Vinyl and vinylidine coatings resistant to moisture and chemicals, acids and alkalies.
3. Quick drying, corrosion resistant primers and undercoats containing zinc chromate and iron oxide.
4. Acid, alkali, and other chemical resistant coatings of chlorinated synthetic rubbers.
5. Spray packaging compounds to resist atmospheric conditions (applicable to pieces varying in size from a bolt to a tank) made of vinyl or ethyl cellulose base.
6. Electrical insulation.

During the war several new techniques were developed or improved to a substantial degree, including the following:

1. Flow coating or hosed-on finishes for protecting large surfaces where appearance is secondary.
2. Application of hot melts to small parts, such as dipping the parts into molten compounds for corrosion protection.
3. The spray application of similar compounds in solution form. These compounds tend to web and to bridge over large openings, forming a continuous film over a rough skeleton made of wood, tape, or cheesecloth.
4. The improvement and refinement of automatic spray equipment to where it is applicable to the finishing of objects of complex shape.

New finishes of broad usefulness are now applicable as a result of war development. Among these are finishes which bake quickly at high temperature (up to 700° F. and as quickly as in a few seconds). These finishes are described in more detail by Mr. Zahn in the article immediately preceding. They are obtainable either clear or pigmented in many colors. The base is a thermosetting resin with high chemical resistance. Obviously they are applicable primarily to conveyerized finishing processes.

Second, we have some new finishes with hammered-like appearance. One coat may be sufficient, using ordinary spray equipment. The finish is smooth but looks rough and is highly decorative. It hides weld marks, scratches and other defects in the base metal.

New coating materials for plastics can also be used effectively and economically. A high grade, abrasion resistant, and highly decorative coating may be applied over a low priced, dark colored base. These coats may be air dried or baked, producing a final product which rates high in appearance, resistance to wear and to corrosion, but is much lower in price than a coating made of solid colored plastic.

Improved vinyl finishes and modified synthetic rubbers are now available; they are air drying or baked materials with high chemical resistance.

Finally may be mentioned the 100% solid resin-impregnating compounds newly developed for electrical insulation which bake to a very hard coating with high dielectrical qualities and moisture resistance.

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(Continued on page 1080)

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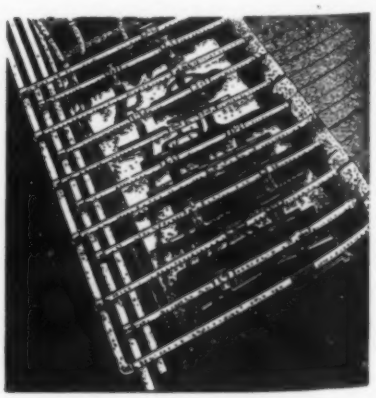

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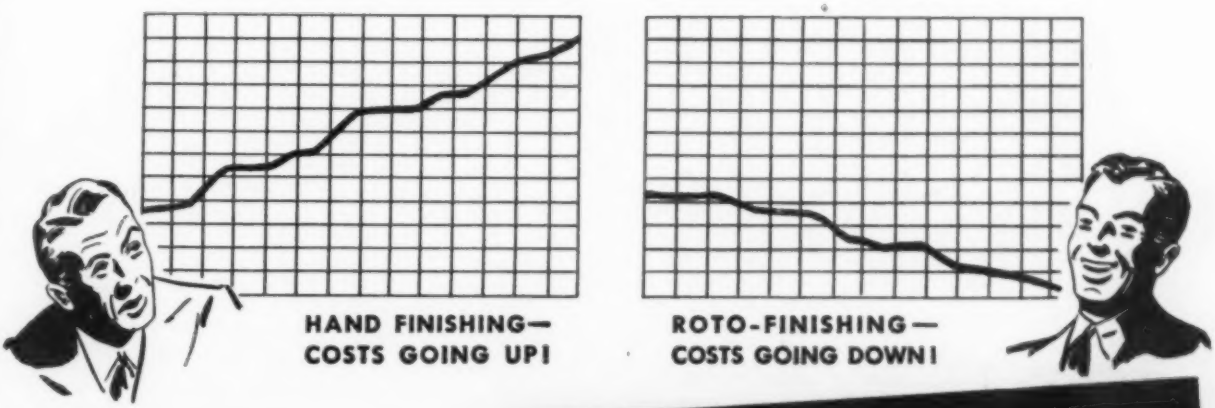

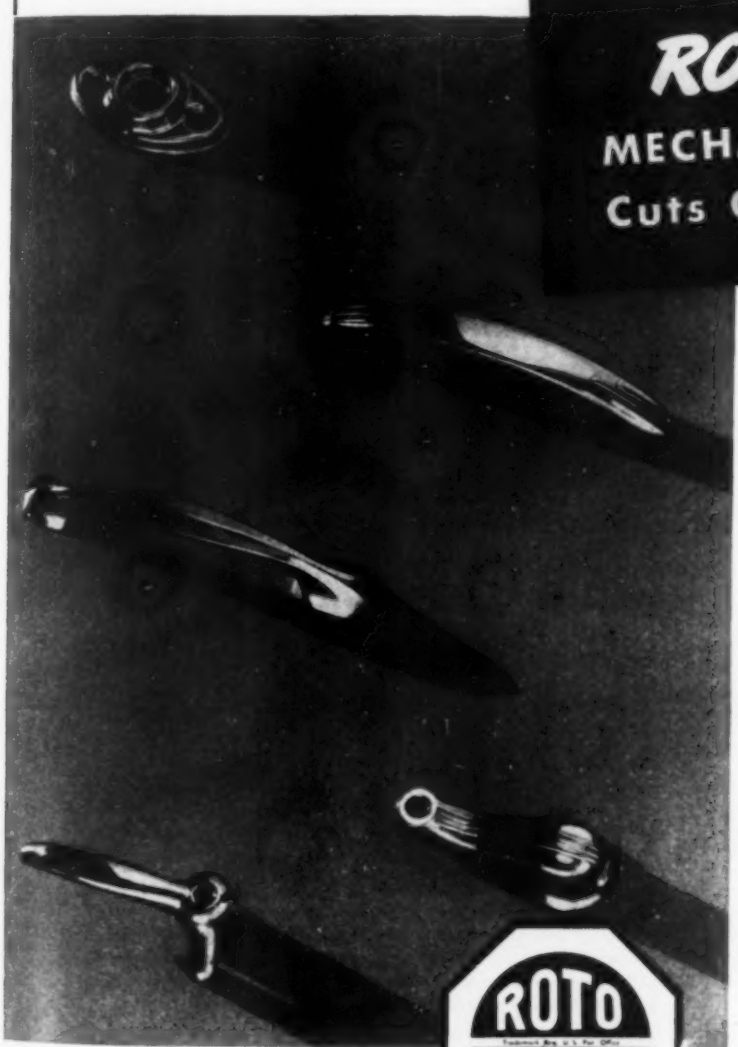

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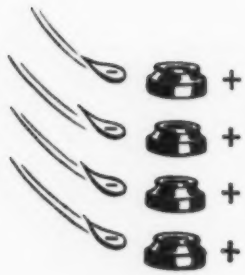

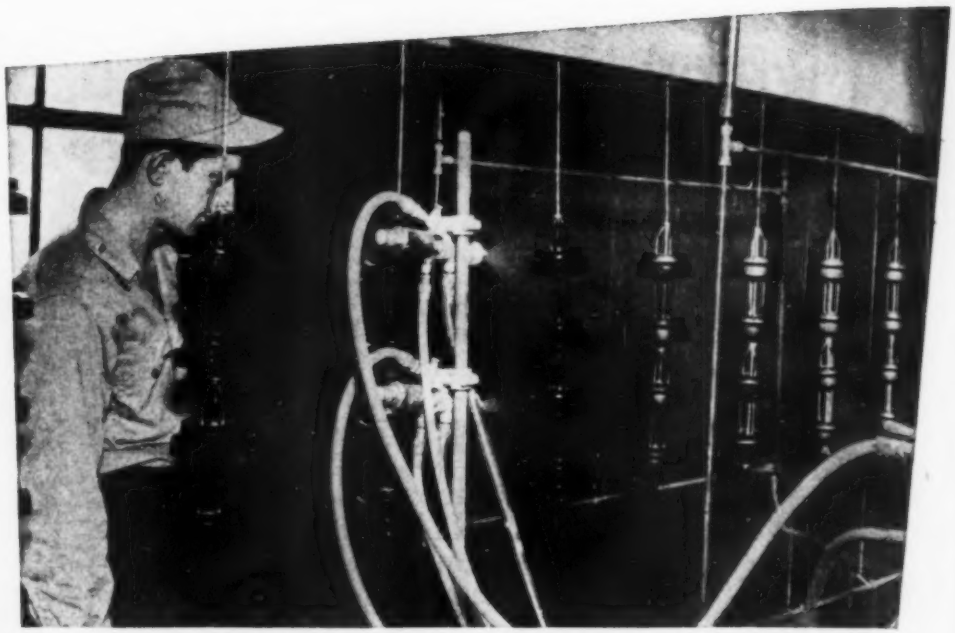

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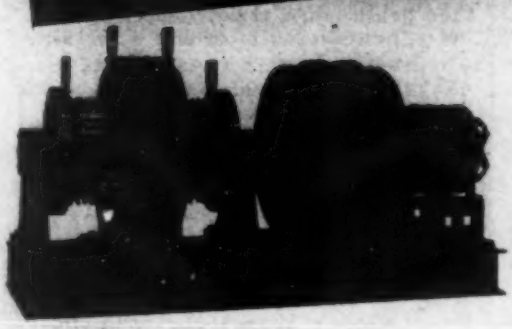

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Electrolytic Polishing of Metal Samples

Compiled (1942) by G. E. Pellissier, Jr., Harold Markus, and Robert F. Mehl

Metal	Solution	C.D.§	Voltage	Temp. °C.	Time Min.	Remarks	Reference
All carbon steels, martensitic, pearlitic, and sorbitic; Armco and white cast iron; 3% silicon steel	Acetic anhydride, 765 cc. Perchloric acid*, 185 cc. sp.gr. 1.61 (65%) Distilled water, 50 cc. 0.5% Al	4 to 6	50†	<30	4 to 5	Prepare solution 24 hr. before using. Use moderate agitation. Al increases viscosity which permits more vigorous agitation and current density of 3. Can use at current density of 10 for austenitic steels. Prepare samples to 000 paper. Fe or Al cathode.	1
Steels (except low carbon)	Perchloric acid*, 54 cc. of 70% concentration Water, 146 cc. Alcohol with 3% ether, 800 cc.	2 to 6	70†	Room	½	Preliminary smoothing on 60-grit alundum wheel; stirring paddle set close to specimen operates at all times.	2
Austenitic steels‡	Acetic anhydride, Perchloric acid (65%) 2 parts to 1 part*	6	50†	<30	4 to 5	Same as items at top of column.	1
Iron and silicon-iron	Orthophosphoric acid sp.gr. 1.316	0.6	0.75 to 2.0			Iron cathode.	3
Tin	Perchloric acid* (sp.gr. 1.61), 194 cc. Acetic anhydride, 806 cc.	9 to 15	25 to 40†	15 to 22	8 to 10	Stir solution if length of electrolysis is over 10 min. Polish to 000 paper. Tin cathode. Electrodes 2 cm. apart.	4
Copper‡	Orthophosphoric acid sp.gr. 1.3 to 1.4	0.65 to 0.75	2	Room	>5	Polish to 0000. Copper cathode. Electrodes 2.2 cm. apart.	5
Copper‡	Pyrophosphoric acid 530 g. per l.	8 to 10	1.6 to 2.0	15 to 22	10 to 15	Polish to 00000 paper. Copper cathode.	6
Cobalt	Orthophosphoric acid sp.gr. 1.35		1.2			Rough metallographic polish. Cobalt cathode.	7
Aluminum‡	Perchloric acid* (sp.gr. 1.48) Acetic anhydride, 2 parts to 7 parts	3.0 to 5.0	50 to 100†	<50	15	Allow 4 to 5 g. per l. to enter solution. Polish to 000 paper. Aluminum cathode.	8
Zinc‡	Potassium hydroxide 25% solution	16	6	Room	15	0000 paper. Solution agitated by air or nitrogen. Copper cathode. Electrodes 2.5 to 15 mm. apart.	9
Lead	Acetic acid, 650 to 750 cc. Perchloric acid*, 350 to 250 cc.	1 to 2			3 to 5	0000 paper, horizontal anode. Use current density of 20 to 25 for 1 to 2 min. to remove flowed layer. Copper cathode.	6
Pb-Sn alloy	Same as above	2					6
Tin + 3% Sb	Same as for tin, above	9 to 15	25 to 40†	15 to 22	8 to 10	Same as for tin, above.	4
Copper + 3.2% Co Copper + 2.4% Fe	Orthophosphoric acid sp.gr. 1.35	0.07	2		5 to 10	Polish to 000 paper. Copper cathode. Electrodes horizontal and ⅛ in. apart.	10
Brass, 70-30.‡ (1 constituent)	Orthophosphoric acid 430 g. per l.	13 to 15	1 to 2	Room	10 to 15	File, swirl in 40% HNO_3 45 sec. Large size copper anode horizontal; electrodes ⅛ to 2 in. apart.	11
66.7-33.3 Brass‡	Orthophosphoric acid 990 g. per l.	2.5 to 3					6
Two-constituent 60-40 brass ‡	Pyrophosphoric acid 530 g. per l.	9 to 11	1.9				6
Aluminum bronze; Leaded bronze (85 Cu, 10 Sn, 3 Zn, 2 Pb)	Orthophosphoric acid 990 g. per l.	1 to 2					6
Phosphor bronze, silicon bronze, monel, nichrome, nickel, and ‡ metals	Methyl alcohol (abs.), Nitric acid (conc.), 2 parts to 1 part		40 to 50†	20 to 30	Seconds	Cathode of stainless steel cloth in bottom of dish. Distance between electrodes ⅛ to 1 in.	12

*Explosive Mixture! §Current density in amperes per square decimeter. †External applied voltage. ‡See last item in table.

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By George L. Kehl*
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Room Temperature Casting Resin for Metallographic Mounts

ONE OF THE MOST satisfactory methods for mounting small metallographic specimens is by molding the samples in some appropriate plastic, such as "bakelite", "lucite", "tenite", and others. These mounting materials, after molding, possess very desirable characteristics for the purpose intended — for example, they are relatively hard and consequently polish well with minimum clogging of emery papers; they are chemically resistant to the usual etching reagents; they are electrically neutral and cause no differential etching between the specimen and the mount; and some are advantageously transparent and nearly crystal clear.

In order to mold these materials properly, the technician must apply simultaneously both heat and pressure. When mounting most of the common metals and alloys this circumstance is of little consequence, but the applied pressure may cause serious deformation in many soft metals, and some alloys may suffer structural changes due to the relatively high molding temperatures required.

To eliminate the disadvantages associated with the usual techniques when mounting some metals at elevated temperature mounting techniques, a transparent plastic has been formulated which can be cast at ordinary temperature. This resin, after preparation, is essentially a partially polymerized methyl methacrylate monomer that is allowed to harden and become completely polymerized after casting by techniques to be described. The resin requires no pressure for molding; the temperature necessary for proper setting need not exceed approximately 120° F. (50° C.); and the final mount after hardening possesses all the desirable attributes of a satisfactory mounting material listed above. Its behavior during grinding and polishing is comparable to that of the conventional lucite mounts secured by heat-pressure molding techniques.

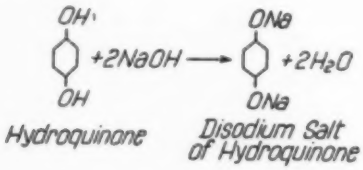
Method of preparation combines some of the features of U. S. Patent No. 2,101,061 which is held by E. I. du Pont de Nemours, as well as methods believed to be original. A methyl methacrylate monomer suitable for raw material may be secured from Rohm and Haas Co., Washington Square, Philadelphia, under the proprietary name of "Cement X". Because of the high volatility and vapor toxicity associated with "Cement X", the preparation of the resin should be carried out in a suitable fume hood.

As supplied by the manufacturer, this monomer contains hydroquinone that serves

*The experimental work described was carried out under contract between the University of California and the Manhattan District, Corps of Engineers, War Department. Mr. Kehl is now associated with the department of metallurgy, School of Mines, Columbia University in the City of New York.

principally to inhibit premature polymerization during storage. The first step in the preparation of the casting resin therefore consists of removing completely the hydroquinone present. This is accomplished in a separatory funnel by treating at ordinary temperature approximately one liter of "Cement X" with a solution of sodium hydroxide (5% NaOH by weight).

This chemical separation proceeds according to the following reaction:



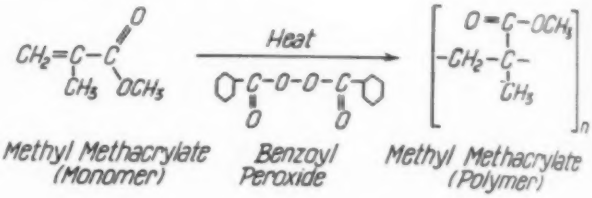
The disodium salt formed is a red-appearing compound that is soluble in water but insoluble in methyl methacrylate. To insure complete elimination of the inhibitor, extractions are continued until the sodium hydroxide solution remains clear while in contact with the monomer. Approximately 850 ml. of solution will be required for complete extraction.

The inhibitor-free monomer is then dried for approximately 15 hr. over anhydrous sodium sulphate (Na_2SO_4). The salt is removed by filtering, and the monomer is again dried for another 15 hr. with anhydrous sodium sulphate and again removed subsequently by filtration. Approximately 400 g. of salt are required for each drying operation. It is essential after drying that the monomer be kept from intimate contact with moisture, since the presence of water will precipitate polymer in a granular form.

To serve as a catalyst in subsequent polymerization, 0.1% by weight of benzoyl peroxide (Eastman Kodak Co.) is dissolved into the water-free monomer. The solution is allowed to stand for about 15 hr. and is then filtered to remove a slight precipitate.

The solution is then placed in a round-bottom flask fitted with a reflux condenser, a mercury-sealed stirrer, and a thermometer adjusted to read liquid temperature. Ten per cent by weight of lucite molding powder (du Pont methyl methacrylate polymer) is added to the solution to initiate chain growth. The mixture is then heated in a water bath, and the temperature is allowed to rise to 175° F. (80° C.). The reaction mix is held at this temperature until the polymer is completely dissolved and the appropriate degree of polymerization has been secured, as indicated by the solution attaining a viscosity approximately equivalent to that of concentrated sulphuric acid (specific gravity of 1.84).

The polymerization of the monomer proceeds as follows:



When the appropriate viscosity of the solution has been obtained — after about 2 hr. (or less) at the reaction temperature — the polymerization reaction is quickly arrested by immersing the flask into an ice bath. The partially polymerized resin may now be cast — in a manner to be described — and subsequently hardened, or the viscous solution may be preserved for approximately 30 days if it is stored under refrigeration, not exposed to sunlight, and the glass container is tightly stoppered.

It is essential during the partial polymerization process that the temperature does not exceed 175° F. (80° C.). If this should occur, it is likely that the reaction will suddenly go to completion with a marked evolution of heat and form a hard, foam-like brick.

Casting Procedure — The technique of mounting a metallographic specimen is relatively simple, and the procedure is similar in part to that followed in mounting small specimens in other casting materials, such as sulphur or low melting point alloys. A micarta or other inert plastic ring, appropriately roughened or scored on the inner surface, and approximately 1 in. inside diameter by ¾ in. high, is placed with one of its edges in contact with a glass plate. The specimen is then placed within the ring, with the surface of interest in contact with the glass plate, and sufficient resin is poured to cover the specimen, plus an excess of about half that amount to compensate for shrinkage during hardening.

To accelerate polymerization after casting, the mount is placed under an ultraviolet lamp and the temperature of the mount maintained at approximately 120° F. (50° C.) by adjustment of the lamp-to-mount distance. Higher temperatures are to be avoided because bubbles will then form within the casting; temperatures lower than that recommended will increase considerably the time required for thorough hardening. Properly prepared resin will harden under the recommended conditions in 2 to 3 hr., and will have a hardness of about 65 to 85 on the Rockwell M-scale. If for any reason the entire retaining ring must be filled with resin, additional plastic may be added and subsequently hardened in small increments.

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Microradiography With Routine X-Ray Equipment

RADIOGRAPHY depends on the differential absorption of X-rays by nonhomogeneous elements in a specimen. Although ordinary techniques are quite suitable for the detection of gross discontinuities, they do not suffice for the study of microscopic discontinuities, since it is impossible to magnify the X-ray images in the same manner that optical images are magnified by lens systems. Instead it is necessary to register the X-ray images on a photographic plate or film and then enlarge the result. This, essentially, is the process of microradiography, and although several of the larger metallurgical research laboratories have adopted it for the study of microstructures, the techniques are unfortunately still unknown to many potential users.

Within the past few years a number of articles have appeared on the subject. Practically all have stressed the need of a variety of X-ray diffraction tubes which are not available in most foundry and production laboratories. A notable exception was the paper of Woods and Cetrone in *Metals and Alloys* (Vol. 18, p. 1320) which showed that a tungsten target diffraction tube equipped with beryllium windows and operated at low kilovoltages could be used to detect microconstituents in various alloys. These authors also published a microradiograph of an aluminum alloy made while using a glass window, tungsten target tube operated at 15 kv. L. W. Ball likewise demonstrated in a paper in 1944 *Transactions* of the American Foundrymen's Association that a tungsten target tube with a thin window could be used to study segregation in light alloys and leaded bronzes, when operated at 20 to 50 kv.

The purpose of this article is to indicate how the ordinary radiography unit (X-ray tube with tungsten target) found in most foundries may be used for the study of the microstructure of bronzes and other nonferrous alloys and for the detection of graphite and dendritic structure of cast iron.

Theoretical Considerations — Although the literature has covered the theoretical aspects of microradiography quite thoroughly, it is desirable to review a few points. If a photographic film under a specimen containing an inclusion is exposed to a beam of X-rays and is then developed it will be found that the area directly below the inclusion will be blackened to a different degree from the surrounding region. The photographic contrast C between the image of the inclusion and the image of the surrounding region is given by the equation

$$C = k\,(\mu_1 - \mu_2)X_2$$

where μ_2 and μ_1 are the linear absorption coefficients of the inclusion and of the surrounding material respectively; X_2 is the thickness of the inclusion and k is a constant characteristic of the film and processing technique. Apparently, then, two factors which limit the contrast are the thickness of the inclusion and the absolute difference in linear absorption coefficients of the two constituents present. Since absorption coefficients are a function of wave length, it may appear that the characteristic radiation of a variety of X-ray targets would be necessary for microradiographic investigations, and for this reason the process could be only of academic interest to foundries. Yet this is not wholly the case.

*The author wishes to acknowledge the assistance of John R. Lloyd, now of the General Electric Research Laboratories, and of Frederick von Batchelder, John Schaum, and Florence Wiley, all of the Naval Research Laboratory.

Fig. 1 — 200 kv.; 3 min.

Fig. 2 — 100 kv.; 20 min.

Fig. 3 — 70 kv.; 30 min.

Fig. 1 to 3 — Radiographs, Magnified 100 Diameters, Through 0.005 In. of G-Metal. Film-target distance: 11 in. Current: 10 milliamperes. X-ray unit with smaller focal spot used in Fig. 3

When a given kilovoltage is applied across an X-ray tube the distribution of intensity of the emitted spectrum is somewhat similar to the distribution of energy in the spectrum of black body radiation. Further, it is observed that the intensity curve falls to zero for some definite limiting short wave length which depends upon the kilovoltage applied. Thus, when a tungsten target tube is operated at 30 kv., say, continuous radiation is emitted whose wave length begins at about 0.4 Å and continues through the soft (long wave length) region. As the kilovoltage is increased the intensity of radiation increases, and the maximum of the curve and the minimum wave length both shift in the direction of shorter and shorter wave lengths. (It should be noted that nothing has been said about the excitation of the characteristic "K radiation". In the technique described, the tungsten tube is normally operated below the critical kilovoltage which excites this K radiation.)

If a two-phase system is to be studied it may occur that the difference in absorption coefficients between the two components is quite large throughout the whole continuous spectrum emitted by the tungsten tube when operated at a given kilovoltage. By plotting curves showing intensity versus wave length for various kilovoltages and comparing them with a plot of difference in absorption coefficients for the two components against wave length, it may be possible to choose an operating voltage wherein, on the average, a large degree of contrast is obtained over quite a range of wave lengths. The necessary data for these graphs can be found in any physics handbook or text on X-ray theory. For production work, it is desirable that a high intensity of radiation be available at this kilovoltage. Frequently an optimum kilovoltage may be found for maximum contrast by experimentation.

Examples — Using a 250-kv. G.E. industrial X-ray unit of the type frequently found in foundries, a series of microradiographs were taken of a sample of G-metal (88 Cu, 8 Sn, 4 Zn), 0.005 in. thick, at various kilovoltages. Exposures were made at 200 kv. (30 milliampere-minutes), 100 kv. (200 milliampere-minutes) and 70 kv. (300 milliampere-minutes) at distance, specimen to focal

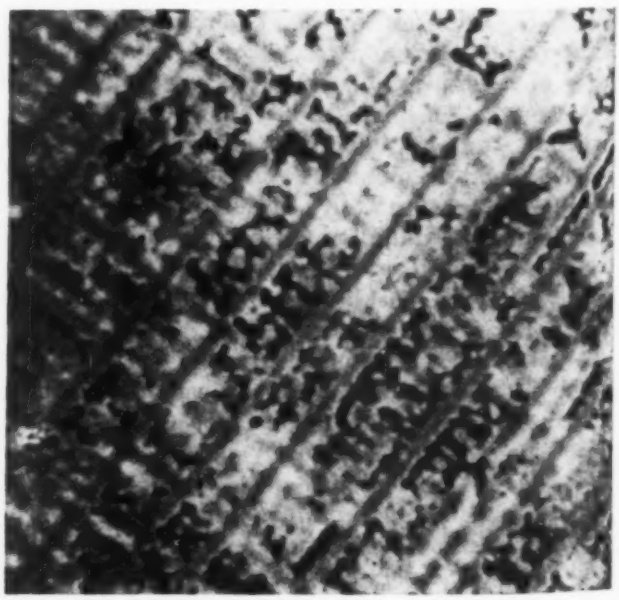

Fig. 4 — Sample of Fig. 1 to 4; Kelley-Koett 150-Kv. Unit With Small Focal Spot; 0.005-In. Copper Filter. 70 kv., 20 min., 10 milliamperes, 8 in. focus-film distance

spot, of 11 in. They were made on the very fine grain spectrographic plate, Eastman type 548-0, and then enlarged 100 diameters photographically.

These microradiographs are reproduced in Fig. 1, 2, and 3 respectively. Of the three, the one taken at 70 kv. (Fig. 3) shows maximum contrast and definition. Since copper, on the average, has a lower absorption coefficient than tin for the wave lengths used, the copper-rich dendrites transmit more of the X radiation to the plate than the segregated tin areas. Consequently the images of these copper-rich dendrites appear dark and the segregated tin areas light, whereas the images of microporosity appear black. The 200-kv. picture (Fig. 1) is blurred; although porosity is quite apparent, dendritic segregation is suggested only by the generally mottled appearance of the radiograph, whereas in Fig. 3, the 70-kv. picture, the dendritic structure and the segregation of tin are readily recognized. Considerable detail unfortunately has been lost because of the several copying procedures before the engravings actually appeared in these pages of *Metal Progress*.

It is common knowledge among radiographers that the definition exhibited by a radiograph is limited by the size of the focal spot of the X-ray tube used. With this in mind the same sample was again radiographed using a 150-kv. Kelley-Koett unit which had a tube with a smaller focal spot. The resulting microradiograph made at 70 kv. (200 milliampere-minutes at 8 in.) showed considerable improvement in both definition and contrast over the negative reproduced in Fig. 3.

Still another factor is worthy of consideration: There is a region of the continuous spectrum where tin has a lower absorption coefficient than copper. This has a deleterious effect on the microradiograph, for in this region the radiation would cause the copper-rich areas to be light and the tin-rich areas to be black. To prevent this a 0.005-in. copper foil may be inserted at the tube head, between specimen and tube. It absorbs a large percentage of this undesired range of wave lengths, and still transmits those wave lengths which provide maximum contrast. Figure 4 is a microradiograph of approximately the same region shown in the previous figures but made with such a piece of foil in place. The improvement over the preceding picture is striking; this was particularly true when the radiographs were viewed directly under the 100-power microscope.

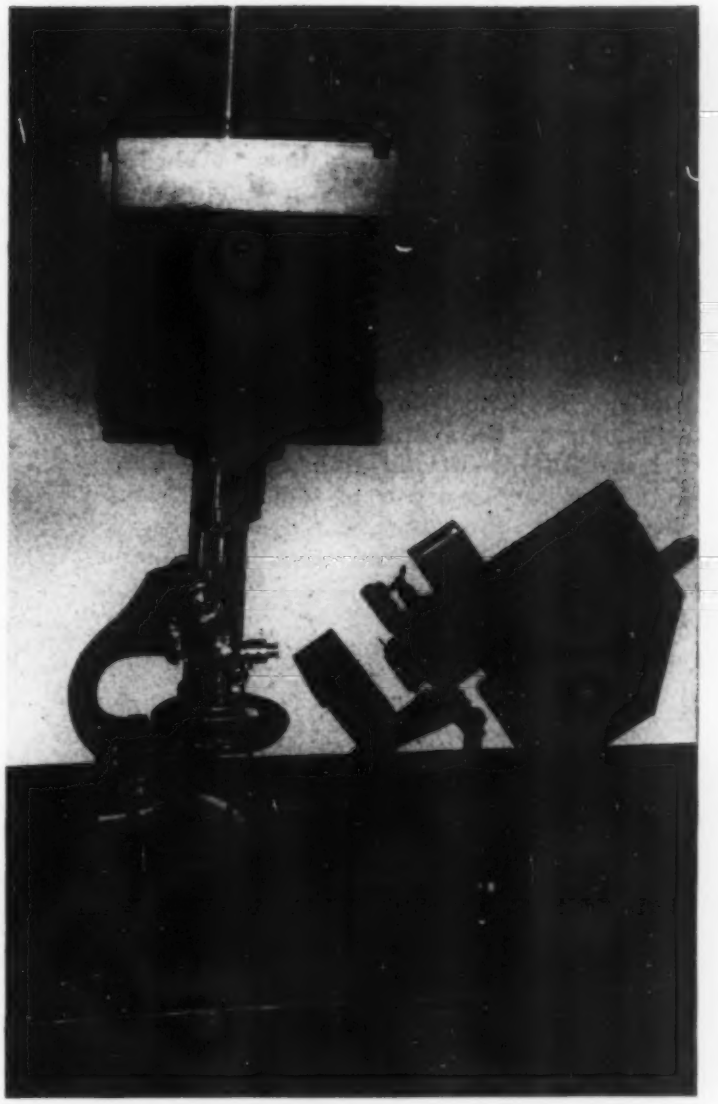

Fig. 5 — Radiograph, Mounted on Slide and Covered, Ready for Enlargement by Microscope and Camera With Transmitted Light — Sub-Stage Mirror and Lamp at Right

Preparation of the Sample — The formula cited for photographic contrast would seem to indicate that specimen thickness need be only a minor consideration. Yet if the specimen is too thick the X-ray shadow of one inclusion may overlap that of another and the resulting microradiograph would suffer loss of definition. Furthermore, the exposure time varies logarithmically with thickness. When a tungsten target tube and very fine-grain film are used, it has been found most expedient to use samples 0.005 to 0.008 in. thick for brass, bronze and steel, 0.010 to 0.015 in. for light alloys of aluminum and magnesium, and 0.020 in. for rubber and plastic samples. When the characteristic radiations of diffraction tubes can be used, thinner samples are preferred.

A variety of methods of sample preparation are available; the choice is largely dependent on the material itself, facilities at hand, and personal preference. Suggested methods are as follows:

A thin section may be cut out of the casting and one side of the specimen then polished. If great care is taken the unpolished side may be milled down to a proper thickness, providing the metal is not too porous. The specimen may also be mounted on a magnetic chuck and a surface grinder used; nonferrous alloys may be mounted in a steel jig or vise which, in turn, is placed on the magnetic chuck. The specimen may also be mounted in lucite with the unpolished surface facing out, and the mount taken down on a lathe. One method of cutting thin slices in a very short time is with a pair of thin rubber-bonded wheels mounted on the same spindle, between which is placed a 0.015-in. shim. Still another method consists of cutting a sliver of material out of the specimen with a band saw.

The author, however, prefers to slice off a thin section about 0.03 in. thick with a cut-off wheel, and then to polish one side on Aloxite paper followed by 000 French paper. By heating an L-shaped brass plate over a gentle flame and smearing it with medium or hard deKhotinsky cement, the sample may be securely fixed to the plate. The whole assembly is then easily handled, and by careful use of a grinding wheel, followed by polishing on Aloxite paper, the sample is quickly reduced to a thickness of approximately 0.005 in. Samples as thin as 0.001 in. have been prepared in this fashion. If the sample comes loose during the process it is a simple task to reaffix it. The sample is finally polished on 000 French paper, and removed by again gently heating the brass plate over a flame. (Excess cement may be dissolved from the sample with benzol or some similar solvent, if necessary.) The sample is now ready to be microradiographed, the entire preparation having taken 30 min. — after some practice.

Several articles have described elaborate cameras for use in microradiography. Actually, if the magnification is to be no more than 200 diameters, the original X-ray film or plate need only be wrapped in black paper during exposure. Using an industrial X-ray unit it is possible to expose simultaneously a group of small samples, nested edge to edge, by laying them on a film placed on a table top and then bringing the X-ray outfit over so the tube's target is at a distance between 8 and 12 in. vertically above the film.

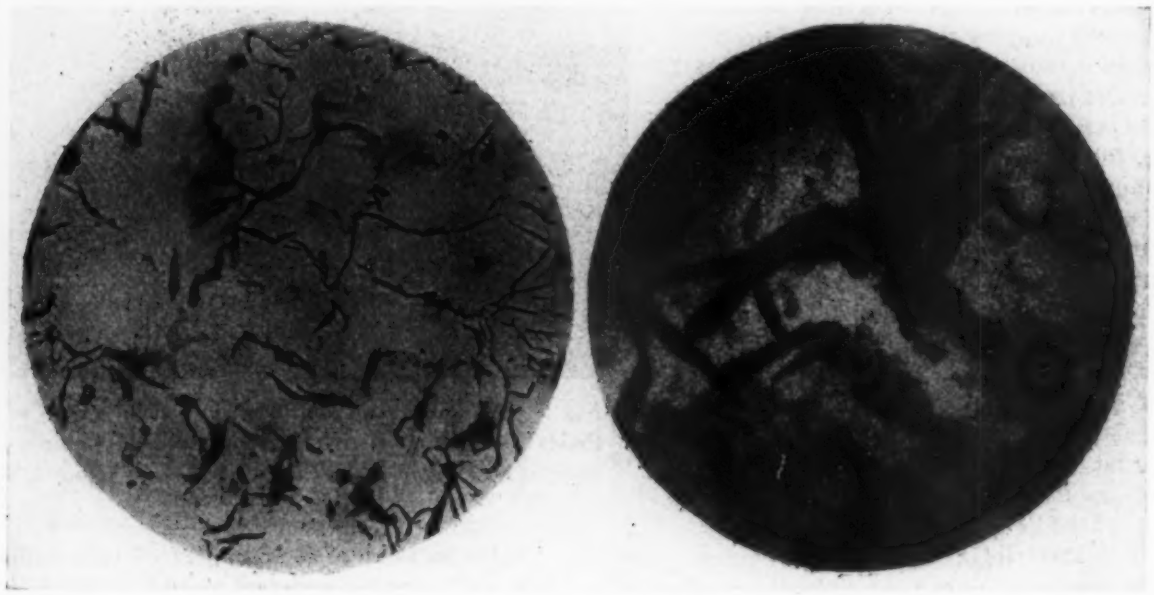

Fig. 6 and 7 — Unetched Microstructure of Gray Cast Iron, Made by Usual Optical Means et 50 Diameters, and Microradiograph of Same Iron at 100 Diameters. (See text for details of plate and exposure)

Choice of Film — Because the radiograph is viewed either under a microscope or is enlarged, the grain size of the film becomes an important factor. Finest grain X-ray film can be used when a magnification up to six times is all that is required. Movie film or type V plates serve well for magnifications up to 40 times, while Microfile film can be used for magnifications up to 80 times providing care is taken in developing. When higher magnifications are desired, Eastman spectro-

graphic films or type 548-0 and 649-0 plates, which have resolving powers of 500 and 1000 respectively, may be used. With great care magnifications of 300 to 400 can be had with type 548 and magnifications of 750 with plates 649; however, such magnifications are useless with a tungsten radiography tube with its inherently large focal spot.

Developers — Ordinarily, developers such as D-8, D-19 or D-72 may be used, the developing time ranging from 1.5 to 5 min. at 68° F., depending on the amount of contrast desired. For very high magnification better results seem to be obtained with a developer similar to Finex (20 min. at 65° F.). For the fixing bath, any X-ray fixer performs adequately. It is advisable to filter the processing solutions daily to remove any suspended matter which may damage the emulsion. If tap water is used for wash, it, too, may need to be filtered. The radiograph may be dried quickly in a warm air blast; but again precautions must be taken to avoid damage to the thin emulsion by excess heat, dirt in the air, or too violent a blast.

Enlargement — Microscopic examination can be made directly if spectrographic plate is used, but if a film has been exposed it is advisable first to mount the film on a microscope slide and cover it with a thin cover slide. Radiographs to be filed away for future use should be permanently mounted. This can be done by securing the cover glass with Scotch tape, collodion or gum arabic. Figure 5, page 1093, shows such a microscope slide assembly mounted on the stage of a microscope. With the camera swung aside, the slide can be moved about until a particularly desirable area is found. The camera is then swung back into position and the area photographed. Some caution must be exercised in interpreting either the radiograph or the enlargement, for frequently the spectrographic film may contain small pits or similar artifacts which may lead to wrong ideas.

Fig. 8 — Dendritic Microstructure of Cast Iron at 50 Diameters by Optical Microscope

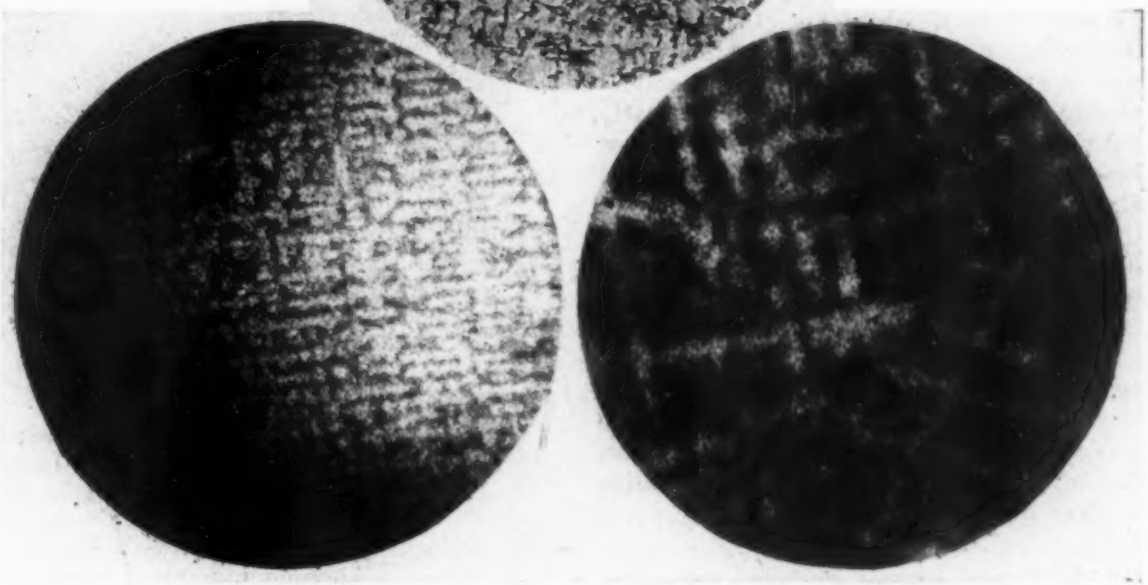

Fig. 9 and Fig. 10 — Same Cast Iron as Fig. 8 at 30 and 100 Diameters, Radiographed on Fast Coarse-Grained Plate and Slow Fine-Grained Plate Respectively

Additional Examples

Having described the technique, several additional microradiographs are reproduced to show what can be done with tungsten radiation in the study of graphite and the dendritic structure of cast iron. These exposures were made with the 150-kv. radiography unit operated at 60 kv. at a distance of 8 in. from the sample. Although photo-

micrographs are included for comparative purposes, metallurgical interpretations are not within the province of this paper and will not be attempted.

Figure 6 is a photomicrograph at 50 diameters of an unetched sample of a pearlitic gray cast iron containing a small amount of free ferrite. Figure 7 is a microradiograph of the same sample (0.005 in. thick) at 100 diameters, taken on plate 548 with an exposure time of 5 min. at 10 milliamperes. In both engravings the graphite appears as black flakes.

A photomicrograph of another cast iron sample at 50 diameters is shown in Fig. 8, while Fig. 9 is a microradiograph of the sample at 30 diameters made on type V plate (30 sec. at 5 milliamperes and 60 kv.), while Fig. 10 is at 100 diameters made on type 548 plate (5 min. at 10 milliamperes and 60 kv.). These three examples are probably sufficient to show that the relatively fast type V plate can be used successfully for low magnifications but that at higher magnification it is advisable to go to types 548-0 and 649-0.

A final additional microradiograph may be interesting as an example of what can be done with the light alloys. Figure 11 is a microradiograph at 30 diameters on plate 548 of a 4% copper-aluminum alloy in the as-cast condition. Tungsten radiation at 35 kv. for 10 milliampere-minutes was the exposure technique. In this picture the copper-aluminum eutectic segregations are white, while the aluminum-rich solid solution is dark. The black areas are voids.

Microradiography Versus Photomicrography

To offer microradiography as a substitute for photomicrography would be presumptuous indeed. Microradiography is an auxiliary tool to be used with discretion by the metallurgist. As with all processes, it has its advantages and disadvantages. Among its advantages are the facts that neither etching nor fine polishing are required. This means that the "polishing" process can be carried out with considerable ease. Again, distortion of surface layers is almost unavoidable when preparing certain alloys for photomicrography. Leaded bronzes, in particular, are very difficult to handle, for the lead may be lifted out of the surface while polishing such samples. The resulting photomicrograph is easily misinterpreted, for the cavities that are registered may have been due to pulled-out lead and not true porosity. On the other hand, if any lead has been pulled out of the surface, the lead remaining underneath will nevertheless cast its shadow-image on the microradiograph. In addition to lead there are hard chemical compounds in other alloys, such as $AlCr_7$ which tend to be pulled out of the base metal when an aluminum-chromium alloy is polished. These loose particles scratch the surface during the final polishing stages, making it extremely difficult to obtain scratch-free photomicrographs. Because such a fine polish is not necessary this problem does not arise in microradiography.

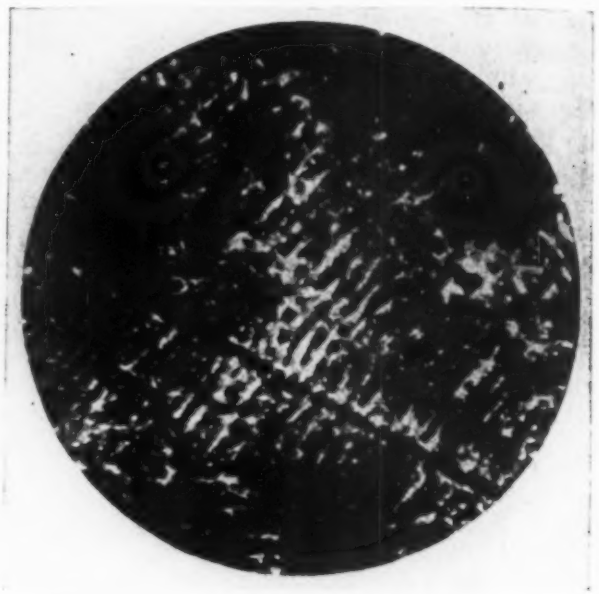

Fig. 11 — Microradiograph at 30 Diameters of 4%-Copper Aluminum Casting. Eutectic is white, solid solution dark, voids black

Again, a photomicrograph is a reflection picture, showing only the surface aspects of the metal. A microradiograph, on the other hand, is a transmission picture, and projects the actual three-dimensional structure of the metal. Thus, where the true shape and distribution of segregated particles or phases are important, microradiographs should be made.

The greatest limitation of the new technique seems to be the limit in magnification obtainable. Next is the fact that with certain alloys it may be found that the photographic contrast is too small for good registry when continuous radiation of a tungsten tube is used. It may then be necessary to resort to the characteristic K radiation of some other target material. A complete account of this latter technique, along with an interesting historical development of the art, may be had from two articles by G. L. Clark in *Transactions* for 1940 and in *Industrial Radiology* for January 1942, and two others by S. E. Maddegan in *Journal of Applied Physics* for 1944, and in *Metals Technology* for February 1944.

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Use of Coated Lenses for Metallography

ALTHOUGH a great deal of publicity has been given to the use of low-reflectance coatings to eliminate glare in photographic work, little data have been published on the use of such coatings for metallographic examination. (A recent article on the subject is "Antireflection Films for Metallographic Objectives", by James R. Benford, *Transactions*, V. 36, 1946, p. 452 to 472.) Therefore, it is the purpose of this article to present comparison photomicrographs showing the advantages of fluoride-coated objective lenses over uncoated objective lenses using several different types of metallographic samples.

A coating composed of fluoride compounds having a low index of refraction was applied to the lenses, without heat, using a high-vacuum technique. This produces a hard, uniform film approximately ¼ wave length, or about 0.000,006 in. thick. The film was applied by Acra Instruments, of Hollywood, Calif., to two achromatic objective lenses — 16-mm. with 0.25 numerical aperture and 4-mm. with 0.85 numerical aperture — both used on a Busch Metaphot microscope.

In contrast to early methods of coating, the new technique is readily applicable to any type of optical system including existent equipment, regardless of how the individual lenses are assembled and mounted. In the coating operation the lenses need not be removed from their individual cells or uncemented, because no heat is used in depositing the coating. Each objective is disassembled so that the lens surfaces are accessible. Both surfaces of the lenses are coated. The coating is sufficiently stable to withstand exposure to any normal atmospheric condition and hard enough to resist common use in handling or cleaning.

Photomicrographs were taken at 100 and 500 diameters with the uncoated lenses. The same lenses were then coated, remounted in the original equipment, and similar photomicrographs were taken of the same areas. The metallographic specimens were kept in a desiccator to prevent oxidation while the lenses were being coated. Illumination for both sets of micrographs was the same; the light source consisted of a tungsten filament lamp and green filter. The vertical illuminator consisted of a diagonal glass reflector.

In order to produce negatives of approximately the same density (as measured by a photo-electric densitometer), it was necessary to reduce the exposure time when using the coated lenses. The 16-mm. objective with 0.25 numerical aperture required approximately one-sixth less exposure time after coating, and the 4-mm. objective with 0.85 numerical aperture required one-fourth to one-third less exposure time.

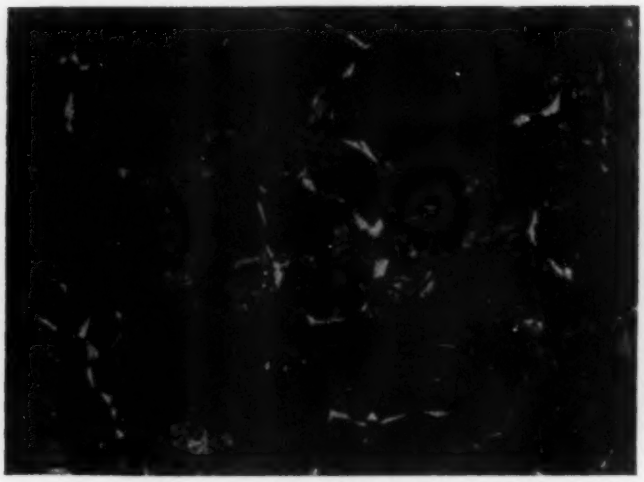
A comparison of the micrographs shows that the fluoride coating increased the contrast of the negative and decreased the over-all glare. The increase in contrast is greatest with subjects having a wide range of tones, low reflecting power and low contrast. It is in this type of sample that increased contrast and detail are most valuable for metallographic examination. Figure 3 is a good example of this type of sample.

A greater improvement was found in the micrographs taken with the coated lens having the higher magnification. This is because there are more coated lens surfaces in the objective for higher magnification. Since the glare is proportional to the number of lens surfaces, the higher magnification objective shows the more marked improvement.

From the comparisons made, it may be con-

*The author wishes to thank Robert Frazer of the Acra Instrument Co. for coating the lenses, and Miss Marguerite Mitchell and Robert E. Hiller of Triplett & Barton, Inc., for help in the preparation of this report.

Uncoated



Coated

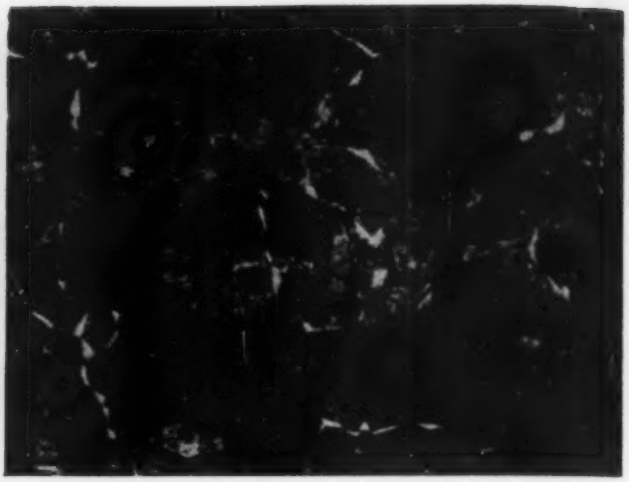


Fig. 1 — Annealed S.A.E. 4140 Steel. Magnification 100×; etch, 5% nital. Note increased contrast and improved detail in dark areas of micrograph taken with coated lens

Uncoated

Coated

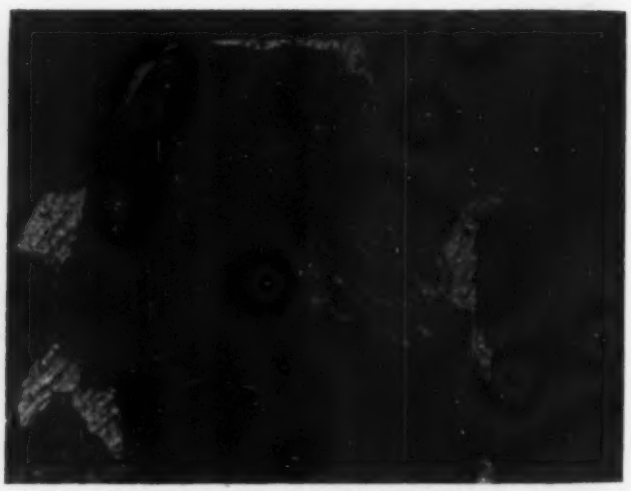


Fig. 2 — Annealed S.A.E. 4140 Steel, as in Fig. 1, but Magnified 500 ×; Etch, 5% Nital

Uncoated

Coated

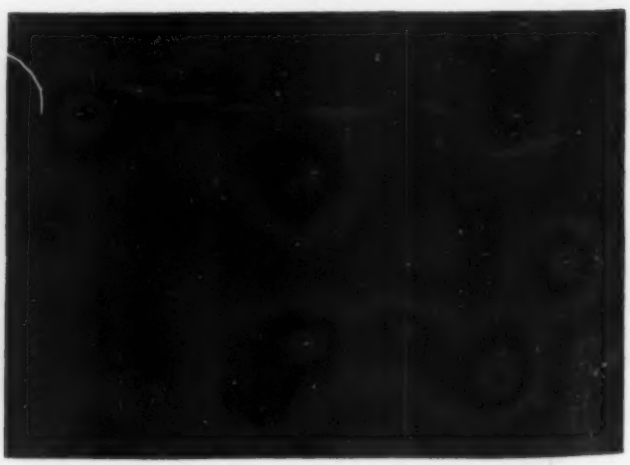


Fig. 3 — Quenched and Drawn N.E. 8740 Steel. Magnification 500×; etch, 5% nital. Note that this type of sample shows the most marked improvement in detail and contrast when photographed with a coated objective lens

Uncoated

Coated

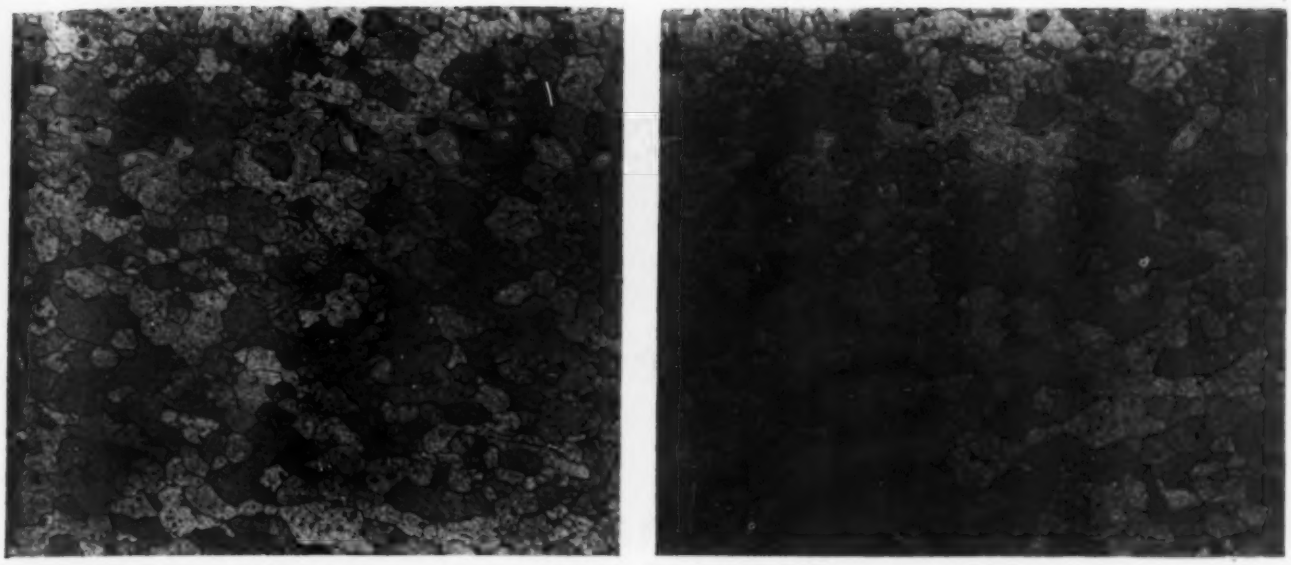


Fig. 4 — 17 S-T Aluminum Alloy. Magnification 100×; Keller's etch. Note that this type of sample shows the least amount of improvement when photographed with a coated objective lens

cluded that a fluoride low-reflectance coating applied to microscopic objective lenses gives the following advantages:

1. Increased negative contrast helps bring out detail in low-contrast samples.
2. Reduced over-all glare gives greater detail in dark areas of photomicrographs.
3. Increased light transmission aids in focusing of dark samples.
4. Reduced exposure time speeds up photographic technique.

To show these improvements in the accompanying micrographs, comparable negatives have been printed for approximately the same length of time on a low-contrast (No. 1) paper. In these studies only the objectives were coated; no treatment was given the eyepiece. If eyepieces were also coated, approximately 15% greater light intensity might be expected to result, but no further marked change in quality of micrographs would be anticipated.

Uncoated

Coated

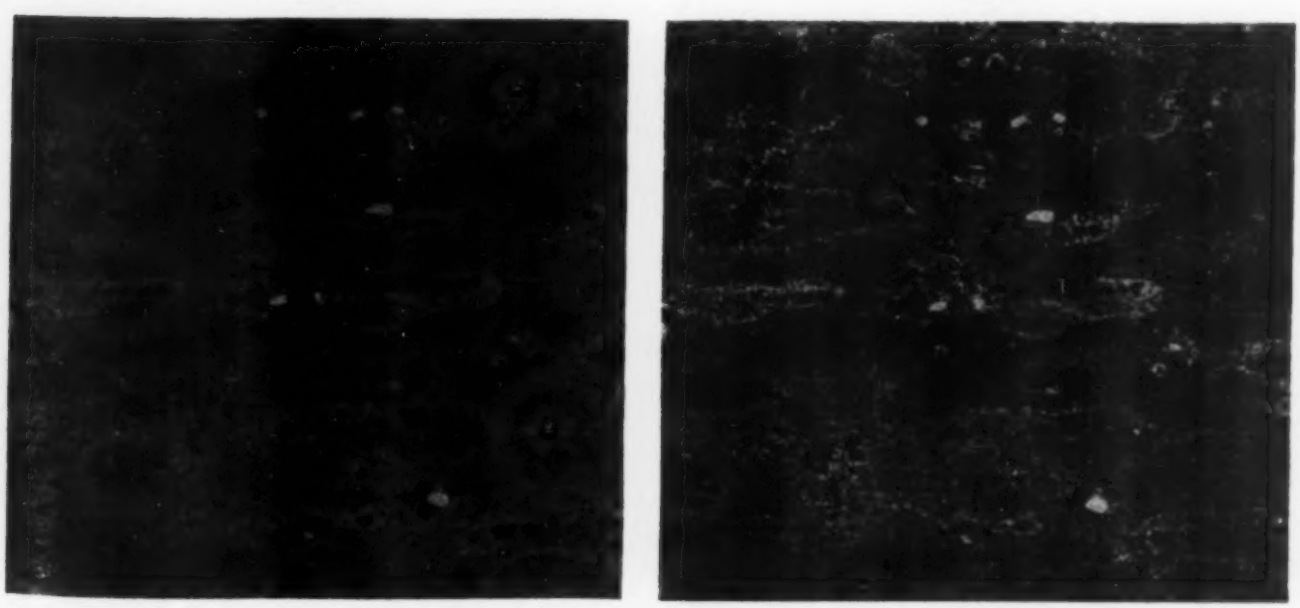


Fig. 5 — 24 S-T Aluminum Alloy Improperly Aged at Elevated Temperature. Magnification 500×; Keller's etch

Screw-Driven Creep-Rupture Testing Machine

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DEVELOPMENT of the gas turbine, accelerated by the war, created new problems for the metal industry — none more crucial, perhaps, than the need for sturdier high-temperature alloys. Those metallurgists who had been searching for better materials to use in chemical equipment, steam turbine and furnace construction, then turned their efforts to alloys that would survive still higher temperatures, under greater stresses, for longer periods of time. Hand in hand with the formulation of these new alloys has gone the need for new and better testing equipment with which to appraise their value.

Since World War I many specialized tests had been devised to study the long-time properties of metal at elevated temperatures. Obviously, if a metal is to endure it must not waste away bodily by corrosion or scaling; its microstructure must be stable at operating temperatures so its other properties will also be stable. It should have a satisfactory (or at least definitely known) resistance to alternating stresses before it can be put into service where the loads are changing — or, if the loads are reasonably steady, the metal must not change its shape beyond safe limits.

As is well known, the last characteristic is known as good creep resistance. Up to a few years ago the usual way to measure this important property was to enclose a tension test piece in a tubular furnace, wherein it could be accurately and steadily heated to a desired temperature. The test piece would be long enough so its ends, protruding from the furnace, could be attached to grips, one hung from a rigid support, the other fixed to a loading mechanism (ordinarily levers and weights). Periodic observation by telescope, through windows in the furnace walls, gave the data whereby an elongation-time curve could be plotted for the given load and temperature. Since a steady stage of extension, uniform for about 1000 hr., was a common objective of the test, and since the load-temperature relationships were often unpredictable, numerous time-consuming tests were required to determine the creep characteristics of one alloy at a single working temperature.

About ten years ago metallurgists at the University of Michigan proposed a shorter method, the "stress-rupture" or "creep-rupture" test, and this has been accepted by researchers in this field — indeed a fortunate circumstance. As described by its originators* "it consists of making a series of tension specimens, surrounding them with small tube furnaces, and adjusting the loads so that fracture occurs in moderate times ranging from a few minutes to a few hours — sometimes much more. The specimens are carried to actual fracture, the time is noted for fracture, and the results, plotted for a given steel at a given temperature, fall on a single straight-line relationship between stress and time for rupture, provided the steel possesses surface and structural stability under the given conditions".

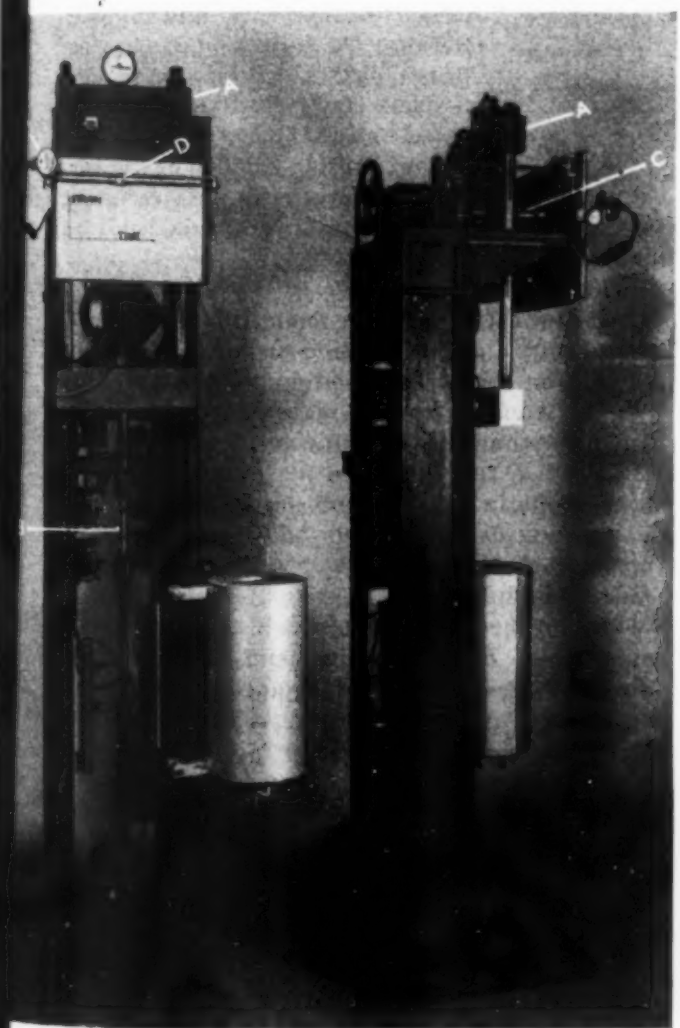
As indicated at the outset, the need for creep-rupture data for high temperature alloys has warranted the construction of much specialized testing equipment. The machine developed by Westinghouse Research Laboratories is notable because it incorporates in its design a number of time-saving and space-saving features which enable it to operate much more quickly and conveniently. The new device uses no weights, requires no extensometer, and automatically draws a creep curve for each specimen tested.

Lever arms and weights are wholly eliminated by the use of a motor-driven screw jack which

*"Stress-Rupture Tests for Heated Metal", by Albert E. White, Claude L. Clark, and Walter G. Hildorf, *Metal Progress*, March 1938, page 266.

loads the specimen through a stiff spring, or force-measuring bar, in series with it. This innovation in design not only frees the operator from the routine duty of manipulating large numbers of weights, but also limits the floor space occupied by a 10-ton machine to an economical 15x15 in. A machine of these dimensions is capable of exerting a sustained pull of 100,000 psi. on a standard 0.505-in. specimen.

In the conventional testing method using gravity weights and lever arms, much time is required to assemble the extensometer, or strain-measuring device. If a distant optical instrument (telescope) is used, fine lines must be scribed on the specimen, or a corrosion resistant target affixed in such a way that it will not influence the test results. If some mechanical extensometer is used, this must be carefully clamped to the specimen within the furnace; parts of it extend to the measuring mechanism outside. No extensometer is needed, however, in the new machine. Instead, "creep" is measured by the travel of the screw jack (C, in the accompanying photograph) in maintaining constant load on the test piece B. The deflection of the force-measuring bar A at any time is indicated by a dial gage mounted upon it.



Front and Side Views of the Creep-Rupture Machine. Essential elements are force bar and dial (A), test specimen (B), jack (C), pen (D) and the clock (E) which is used to drive the pen horizontally

An electrical contact on the dial controls the operation of the motor. Normally, when the required load is on the specimen, the dial indicator stands slightly off this contact. If the specimen lengthens a little by creep, however, a relative motion of the heads of the machine occurs, and pressure on the bar drops off slightly, the dial indicator moves to close the contact, and thereby causes the motor-driven jack to restore load to the bar. When the force-measuring bar is compressed to its original position, corresponding to the desired load on the specimen, the dial contact opens and the motor stops.

Since the test is run at constant temperature and load, the thermal and elastic strains in the system do not vary, and the relative motion of the heads therefore measures only plastic deformation. The minute fraction of this deformation which may occur in the hot parts of the extension pieces and in the threaded heads and fillets of the specimen can be compensated for by determining an "effective gage length", and this is found to depend only on the shape of the specimen and does not vary appreciably from one alloy to another.

Another novel feature of the machine is its automatic recording equipment which traces an individual creep curve for each test. Since the new machine is designed principally to test alloys at high stresses, rupture lives are short, lasting only from 10 to 400 hr. The automatic feature thus disposes of the need for taking strain gage readings every few minutes.

The record is made by a pen D which is driven horizontally over a sheet of graph paper by a clock E and vertically, through a gear train which amplifies the motion, by the travel of the screw jack. When the specimen ruptures, the control circuit (of which it is a part) is broken and the motor and clock both are stopped. An accurate and complete strain-time record is thus secured. Particularly, the final point on the curve, or plastic strain at rupture, is determined with much greater precision than ever is possible by the conventional practice of measuring it after rupture by fitting the two broken ends together.

Another outstanding advantage of the new machine is that it can readily be adapted for short-time tensile tests, constant strain-rate tests, or relaxation tests.

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A Practical Furnace for Vacuum Melting

FREQUENTLY, in the course of metallurgical research or in small scale production of special products, it becomes desirable to melt and cast metals and alloys in vacuum, or at least in a non-reactive atmosphere. The main advantages are obvious — relative freedom from oxidation or reaction with gases other than oxygen, and the elimination of certain gases or volatile impurities present originally in the melting stock.

The furnace to be described in this article has proved very satisfactory for melting and casting 3½-lb. ingots of experimental high nickel alloys, later processed into wire for radio tubes. However, the casting of 5-lb. or even 10-lb. ingots, depending upon density and melting point, would be feasible in this equipment. The lowest pressure obtainable during operation is in the range of a few microns or better, and is a function of the character (volatility) of the charge.

The furnace is heated by a 20-kw. Ajax-Northrup spark gap, high frequency converter (standard melting equipment in many metallurgical laboratories).

As shown in the general cross section on the opposite page, the furnace shell consists of a quartz pipe (sand finish) 6 in. inside diameter and 22 in. long, with approximately ½-in. thick wall, fitted on top and bottom with ends fabricated from steel tubing and boiler plate. All joints in the steel top and bottom are arc welded inside and out to insure vacuum tightness; the welded assemblies are annealed prior to final machining to eliminate internal stresses. The joints between the steel top and bottom are sealed by rubber gaskets. It will be noted that all gaskets are partially recessed in grooves cut in the steel; it is customary to recess the rubber to about one-half its thickness to prevent spreading under pressure. One important consideration in providing gaskets at the ends of the quartz pipe is to allow plenty of width to accommodate the inevitably different diameters at the two ends, and to allow tolerance for future pipes (in case of breakage) which may be slightly off-size. However, the quartz can project slightly over the gasket without causing trouble, as the gasket projects up above the groove in the steel about ⅛ in. It is necessary to specify ground ends on the quartz pipe.

The furnace assembly is conveniently supported and centered in an angle iron frame by a ½-in. transite plate *B* resting on members *C;* the flange *A* on the furnace bottom carries the entire weight. Another transite plate at top, *H*, centers the furnace and holds the furnace head. The furnace head or top is held in place by four equally spaced bolts in flange *D* and top transite plate *H;* by screwing down the nuts both top and bottom rubber gaskets are compressed and the unit is made vacuum-tight.

Atmospheric pressure would pull up everything tight, but the bolts lend stability. On the other hand, bolts are unnecessary on the top cover *E* unless the furnace is to operate with inert gas above atmospheric pressure. There is another reason, however, for the use of hold-down bolts at *E:* In leak testing by means of gas pressure it is necessary to hold the cover down; special clamps made in the form of a square frame with two long screws and cross bars have been used by the author for this purpose.

Adequate water cooling on top and bottom is necessary. This is done by soft soldering ¼-in. copper refrigerator tubing on a large part of the steel surface, as indicated in the drawing.

Another feature incorporated in the furnace

*The author is now Associate Professor of Metallurgy at New York University.

is the side tube at *F* through which can be added small amounts of highly oxidizable or volatile constituents, such as magnesium, after the rest of the charge is melted. (Sometimes an inert atmosphere must be introduced before charging to prevent loss by boiling off; this point is discussed in detail later.) The seal at *F* is the same as the seal at *G*, and is designed to allow a rod to be pushed in or out without disturbing the vacuum. A sectional drawing of this seal at larger scale is shown in Fig. 2, page 1104.

Two additional fixtures should be provided in the head which, for the sake of simplicity, are not shown in Fig. 1. One is a small standard Hoke needle valve to introduce an inert gas or air, and the other is a compression gland for connecting a vacuum measuring device. The needle valve can be screwed into place at any convenient point on the head and made vacuum-tight by painting a little glyptal around the threads. The compression gland is shown in Fig. 3, page 1105, and consists of a brass fitting equipped with a short section of rubber tubing. A tube (usually glass) is inserted, as shown, and the rubber is compressed around the glass by tightening the hexagonal nut.

It is hardly necessary to describe the supporting frame in any detail, but a few words of caution in one respect are worth mentioning: If a steel angle iron frame is used, no part of the steel should come closer than 6 in. to the induction coil — in fact, it would be better to alloy an 8-in. separation. When the steel is too close, induced currents cause undesirable heat. In particular, closed iron loops near the coil are bad; such a loop is formed by the horizontal steel members. Such parasitic heating can be eliminated by cutting out a section of the loop, where rigidity is not needed, as shown for the members supporting the top transite in Fig. 1. Excessive heating can also be largely overcome by covering the

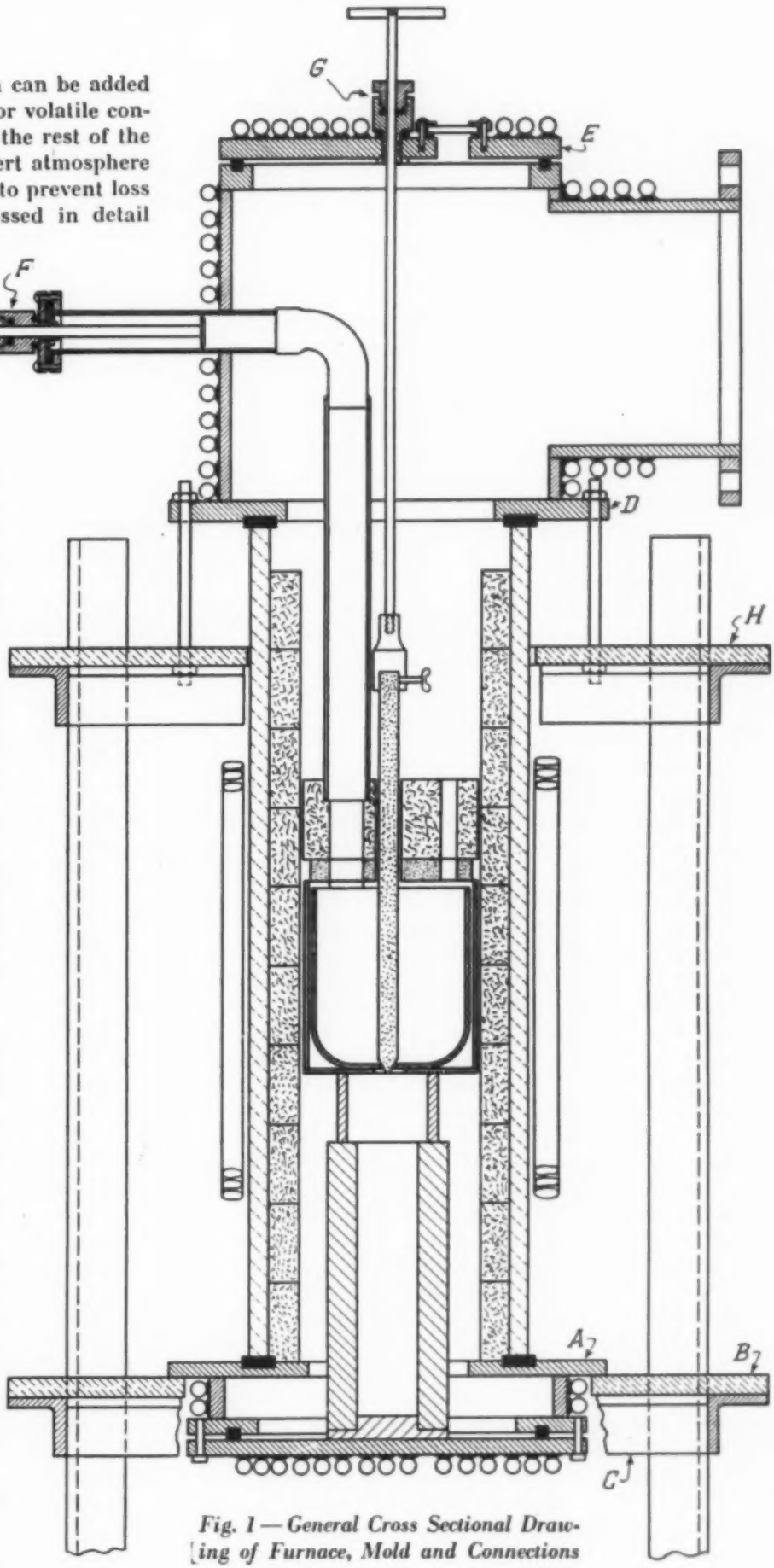

Fig. 1 — General Cross Sectional Drawing of Furnace, Mold and Connections

steel members nearest the coil with copper. Of course, the frame could be made of brass or aluminum or any strong nonmagnetic material; then it would not matter so much how close the coil were approached.

Interior Construction

Referring again to Fig. 1, it will be noted that the inside of the furnace is lined with split rings of K-30 light weight brick made by Babcock and Wilcox. These are cut out on a band saw or hack saw and filed to fit the inside of the furnace; they are about ¾ in. thick radially and a brick's thickness vertically. K-30 is very satisfactory thermally and mechanically, and is readily degassed.

Zircon (zirconium silicate) crucibles, obtained from the Titanium Alloy Mfg. Co., are satisfactory for most metals. They can be rapidly heated and cooled, having a low coefficient of thermal expansion. A central ⅜-in. hole is bored in the bottom of the crucible to drain the metal during casting. It is preferable to order crucibles with the hole in the bottom, as high fired zircon is impossible to drill except perhaps with a carbide glass drill. The stopper rod is also zircon; it is ½ in. in diameter by 10 in. long with a 90° cone ground at one end. The other end is secured into a stainless steel socket with a wing screw; this socket in turn is held by a ¼-in. stainless steel rod passing through the sliding seal *G*. Stainless steel is recommended mainly because of its poor thermal conductivity, but its freedom from rust in damp atmospheres is a consideration, as well as its high melting point.

The zircon crucible is shown inside a graphite heater crucible. This has been found desirable in melting high nickel alloys, for which the furnace was primarily constructed. Some melts have been made without the heater crucible, but there is then a strong tendency for bridging over at the top where radiation is greatest. As soon as the bulk of the nickel charge melts and drains away from the chunks forming the bridge it is impossible to get enough power into the bridge to melt it. The graphite crucible eliminates this difficulty, as the charge then becomes heated by radiation from it rather than by direct induction. It has the disadvantage that the charge is then free of eddy currents and the stirring caused thereby, but there is good evidence that the heat becomes well stirred in the act of pouring.

There also seems to be some slight reaction between the zircon and the graphite, forming carbon monoxide. This reaction does not harm the crucible but the gas formed is troublesome at high vacuum. The difficulties increase after the graphite has been used several times; the reason is not clear, but it may be because of a tendency for the graphite to become rougher at the surface, and hence present more surface for reaction with the ceramic crucible. A molybdenum can rather than the graphite crucible would be an improvement.

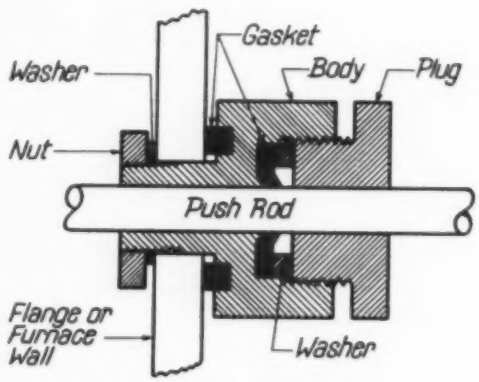

Fig. 2 — Sliding Seal

A small zircon slab (in low fired or a soft condition) covers the crucible. It has one hole bored in the center to pass the stopper rod, and another peep hole bored off center so the experimenter can see inside the crucible. A third hole matches the tube for introducing ingredients after the furnace has been closed. A split K-30 brick cover is cut to fit over the zircon cover for additional heat insulation.

Three types of molds have been used, all plain cylinders 1½ in. inside diameter by 9 in. long. The first molds were simply machined out of graphite and consisted of a graphite tube with a replaceable bottom as indicated in Fig. 1. Next, an alundum tube was inserted along the cylindrical portion to cut down chilling from the sides. Lastly, silica investment molds have been obtained from the Austenal Laboratories, of the type used in precision casting.

Investment molds are probably the most satisfactory from the standpoint of minimum pipe, but they are more expensive since they can be used but once. There is not much difference in pipe in castings made in the graphite molds and the alundum-graphite combination; both yield an open pipe 1.5 to 2 in. deep. The main advantage of the alundum liner is to increase mold life; after several castings the graphite surface is pitted or marred and the ingot can be stripped with difficulty. The alundum liner does not tend to crack from thermal shock, probably because of the rather tight fit between the alundum and the graphite.

As the total length of the casting is only about 7 in., a 1½-in. pipe means a considerable cropping loss. However, as the product is wire of rather

small diameter, and only a small fraction of each ingot is completely processed, this factor has not been troublesome. If attention must be paid to the reduction of pipe, it could readily be done by providing a hot top on the mold.

An alundum ring about 2½ in. long separates the crucible and mold, of proper length to center the crucible in the high frequency coil. The top of the mold is about level with the bottom of the coil; thus the mold is heated somewhat. This must be minimized, however, when casting nickel alloys, to avoid the formation of carbides. With an alundum liner the mold could be heated to any desired top temperature by vertical adjustment. Incidentally, this produces the same effect as a hot top in promoting soundness of the casting.

The Pumping System

The pumping system, to evacuate the furnace and its appurtenances, consists of a mechanical pump and a diffusion pump of adequate capacity; the former is a Kinney C.V.D.-556 compound mechanical pump with a theoretical displacement of 15.2 cu.ft. per min. (7.2 l. per sec.). The diffusion pump is a Distillation Products M.C.-500 metal diffusion pump; it can produce an ultimate vacuum of $5 \cdot 10^{-6}$ mm. It starts operating at a forepressure of 200 to 400 microns with Octoil, depending upon the heater input; the pumping speed is 500 l. per sec. at 10^{-4} to 10^{-3} mm. Actually, Silicone No. 703 from Dow-Corning has been used instead of Octoil because of its resistance to oxidation or cracking; it also allows an inert atmosphere to be introduced without waiting for the pumping fluid to cool down to room temperature.

The mechanical pump is probably adequate, but the use of the diffusion pump warrants a little discussion. Generally speaking, the vacuum system is satisfactory, but sometimes the pressure rises for short periods to the order of a few hundred microns during a particularly gassy melt. It might be preferable to use a booster pump which produces less of an ultimate vacuum, but which can operate at a higher forepressure. It is certain that nothing like $5 \cdot 10^{-6}$ mm. is ever approached during melting, and for most applications such a high vacuum is unnecessary (and perhaps even undesirable). Furnace pressure of the order of a few microns is adequate for practically all work, as this is sufficient to prevent oxidation and to eliminate gases from melts of ordinary metals. If it is necessary to maintain pressures below 10^{-4} mm. at all times, it would probably pay to install a booster pump between the diffusion pump and the mechanical pump, and it might be necessary to use a larger mechanical pump.

In critical applications where even momentary high pressures could cause trouble, it is a good idea to install Pirani gages in the pumping line between pumps. For example, in a three-component system where there is a diffusion pump, a booster pump and a mechanical pump, a gage would be placed between the first two and the second two as well as at the furnace. By switching from one gage to another it is possible to know when the forepressure to either the booster or diffusion pump is close to the threshold pumping value. If it is, the furnace power can be shut off and temperature-rise checked before the pressure starts building up in the furnace.

Leak Testing — A properly constructed furnace should give little or no trouble with leaks; but when first put into operation there will usually be some leaks which have to be stopped. Also an occasional check is necessary.

Experts in this field, such as cyclotron operators, all have their preferred methods for leak testing, and much could be written on this aspect of vacuum equipment. However, for metallurgical work, two methods are quite convenient. For big leaks (of the order of 100 to 200 microns or larger), the pumps are turned off, hydrogen pressure of 5 psi. gage is applied inside the system, the outside painted with a soap solution, and bubbles looked for. Smaller leaks (about 100 microns or less) can be detected with a Pirani gage while playing hydrogen over suspected parts. When a leaking spot admits hydrogen into the system instead of air, the gage shows an upward kick or a deflection toward higher pressure owing to the difference between the conductivity of air and hydrogen. (Other gases are not recommended, although alcohol or acetone may be used, but these substances are not as convenient, and do not get into hard-to-reach places as readily as hydrogen.) A Pirani gage such as the one made by Distillation Products is very satisfactory for this purpose, and is also a very desirable part of the operating equipment. Because it reads continuously and reads condensable gases as well as permanent gases, it is preferable to the more common McLeod gage, and is well worth the difference in cost.

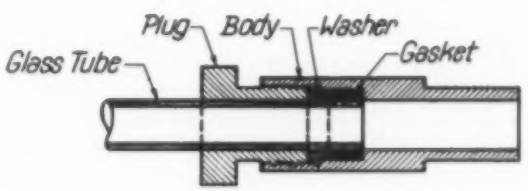

Fig. 3 — Compression Gland

Furnace Operation

Crucibles used in this furnace are 3⅜ in. outside diameter, 4⅝ in. tall, and have a ¼-in. wall, and hold about 1600 g. (3.5 lb.) of nickel or high nickel alloy squares about 1 in. on a side. Molten, the charge occupies less than half the safe crucible height, but it is not feasible to add metal after evacuation without completely altering the furnace construction. In order to increase the charge, a larger crucible could be used, or an alundum sleeve could be placed on top of the crucible to increase the charging height. If this were done, it would be necessary to lengthen the graphite heater crucible accordingly, and also to increase the length of the stopper rods.

After the charge has been placed around the stopper rod, and the zircon crucible slipped inside the graphite heater crucible, the assembly is lowered to rest on the mold-spacer assembly already in the furnace. The zircon and K-30 covers are then put in place and, if desired, part of the charge is placed in the side arm. A 1-in. copper elbow is fitted on the interior projection of the side arm and the downward arm of the elbow fitted to a short length of alundum tubing leading to a hole in both crucible covers. The copper elbow and alundum tube guide the fall of the auxiliary charge into the crucible.

The stainless steel rod and socket assembly is removed from the furnace cover by removing the handle at the top and simply pulling the rod through gland *G;* the socket is then fitted over the top of the zircon stopper rod and the set screw tightened. The rod has a groove ground around the circumference at the level of the set screw to insure that it does not slip when the time comes for casting. Lastly, the cover is fitted into place over the stainless rod and slid down until it is resting on the top rubber gasket.

The system is evacuated in about 15 or 20 min., most of which is consumed by the heating-up period of the diffusion pump. The Pirani vacuum gage should read close to zero, as the minimum pressure which can be read is one micron, and the diffusion pump will do much better than that. Cooling water at top and bottom is turned on and current switched on to the heating coil. When using the graphite heater crucible and there is no danger of heating the charge too fast and cracking the crucible, 20 kw. may be applied from the start. About 30 min. are required to reach 1500° C. (2700° F.). The nickel alloy is then melted and superheated adequately for pouring.

Ordinarily, better results are obtained by casting in an inert atmosphere after vacuum melting. This is because the mold reaches a maximum temperature during casting, and residual gas in the mold walls comes off at the moment of pouring and causes unsoundness, particularly around the outside of the casting.

A furnace could readily be designed in which the mold is heated as hot as the charge, but this would be unnecessary. If inert gas is introduced into the system just prior to pouring, it suppresses any evolution of gas from the mold and the casting is sound. The pressure of the inert gas need not be high — a few millimeters of mercury is usually adequate, but to be on the safe side it is better to add the better part of an atmosphere. On adding this gas, the pumping system is turned off, and the pressure allowed to build up to the desired point. This rise in pressure can be followed very well by installing an ordinary vacuum dial gage (reading in psi. or equivalent units), obtainable at most laboratory supply houses.

When the heat is ready to pour, the stainless steel rod is pulled up. Contrary to expectation, there is little or no leakage around the stopper rod. All that is required is to twist the rod in the hole a few times by hand to secure a reasonably good fit over a very short length of the cone. The surface tension of the melt is such that leaking is very unlikely.

In vacuum melting, materials must be selected carefully to exclude highly volatile constituents such as manganese or zinc. In melts where these constituents are desired, it is possible to use an inert atmosphere from the start. In this practice, the furnace would be pumped out while cold, and an inert gas such as nitrogen or argon (purified to the desired extent) would be added. Pressure should be less than one atmosphere because volume will expand during heating. Half an atmosphere or less will be adequate for most volatile metals; the best amount can be found by test.

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Damping Capacity*

SINCE THERE is good reason for suspecting an association between damping capacity and fatigue strength, a method was developed to investigate these properties simultaneously for some aluminum alloys. Equipment for the excitation of resonance vibrations and for the measurement of damping capacity is described.

The damping capacity equipment was designed to reduce to a minimum all loss of energy other than that due to the damping capacity of the material being tested. The specimen is suspended freely by a fine steel wire within the exciter and the detecter coil systems. The changes in damping capacity have been observed during continuous vibration at surface shear stresses up to 22,400 psi. A high frequency of stress alterations of the order of 1500 cycles per sec. is used while the specimen is vibrated torsionally at the resonance frequency. The alternating torque is applied electromagnetically and the maximum surface shear stress developed depends on the damping capacity of the specimen. In terms of damping capacity, the total external loss, including leakage through the suspension wire, electromagnetic damping and air friction, is 0.0022%. For aluminum alloys, at least, the error introduced by the heating effects of the exciter is not serious.

Aluminum and all aluminum alloys so far examined were found to be similar in their characteristic variation of damping capacity with strain, although the actual curves for each material are widely separated. The damping capacity is low at low and moderate strains but increases rapidly when a certain critical strain, dependent on heat treatment, is exceeded. For example, these critical strain values for Hiduminium RR 56 (2.12% copper, 1.12% nickel, 1.03% silicon, 0.82% magnesium, 0.75% iron, 0.06% titanium and 0.04% manganese) correspond to surface shear stresses of 1210, 4345 and 14,560 psi. for annealed, normalized and annealed, and fully heat treated material, respectively. The critical

(Continued on page 1110)

*Abstracted from "Damping Capacity and the Fatigue of Metals", by R. F. Hanstock and A. Murray, *Journal* of the Institute of Metals, V. 72, p. 97 to 132.

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Damping Capacity

(Continued from page 1108)

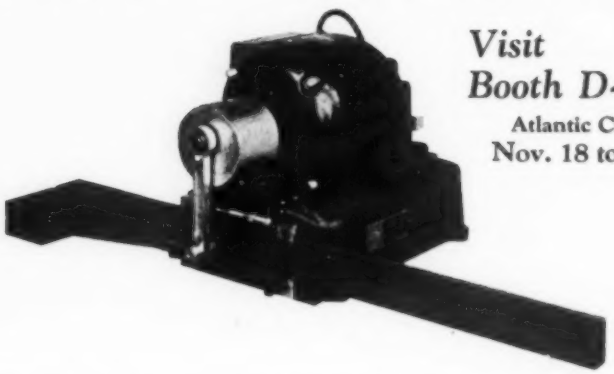
vibrational strain of aluminum alloys varies roughly with the limit of proportionality.

Magnesium alloys have a similar relationship between damping capacity and strain. Aluminum content in magnesium alloys has considerable influence on their critical strain. On the contrary, there appears to be no critical strain for copper. With 0.6% carbon steel, the condition of the steel seems to have an appreciable effect on the relation between damping capacity and strain; in the quenched condition, it exhibits a critical strain whereas no critical strain is observed in the quenched and tempered steel within the range investigated.

The changes in the damping capacity of specimens of aluminum and magnesium alloys during vibration at a stress above the critical value are associated with strain hardening and fatigue, the former being indicated by a gradual decrease and the latter by a gradual increase in the damping capacity. An increase in damping occurs as a result of the formation of fatigue cracks, and at a given vibrational stress, it appears that the time rate of this increase may be indicative of the endurance of the material.

It is evident that the damping capacity of a metal depends very sensitively on the composition and metallurgical state of the metal, as external losses are eliminated. The damping capacity values obtained are much lower than previously reported values but it is believed that they are much more accurate. At least for aluminum alloys, the intrinsic damping capacity will exert very little control on the development of vibrational stresses below those stresses at which fatigue occurs. Consequently, for long endurance, it may be desirable to select materials having a high critical strain and a low damping capacity at strains less than the critical value. If the hypothesis that a high rate of increase in damping capacity implies rapid failure by fatigue is substantiated, a quick fatigue testing means will be available for further work.

PLATE TESTING



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Exposure Chart for Bausch & Lomb Research Metallograph

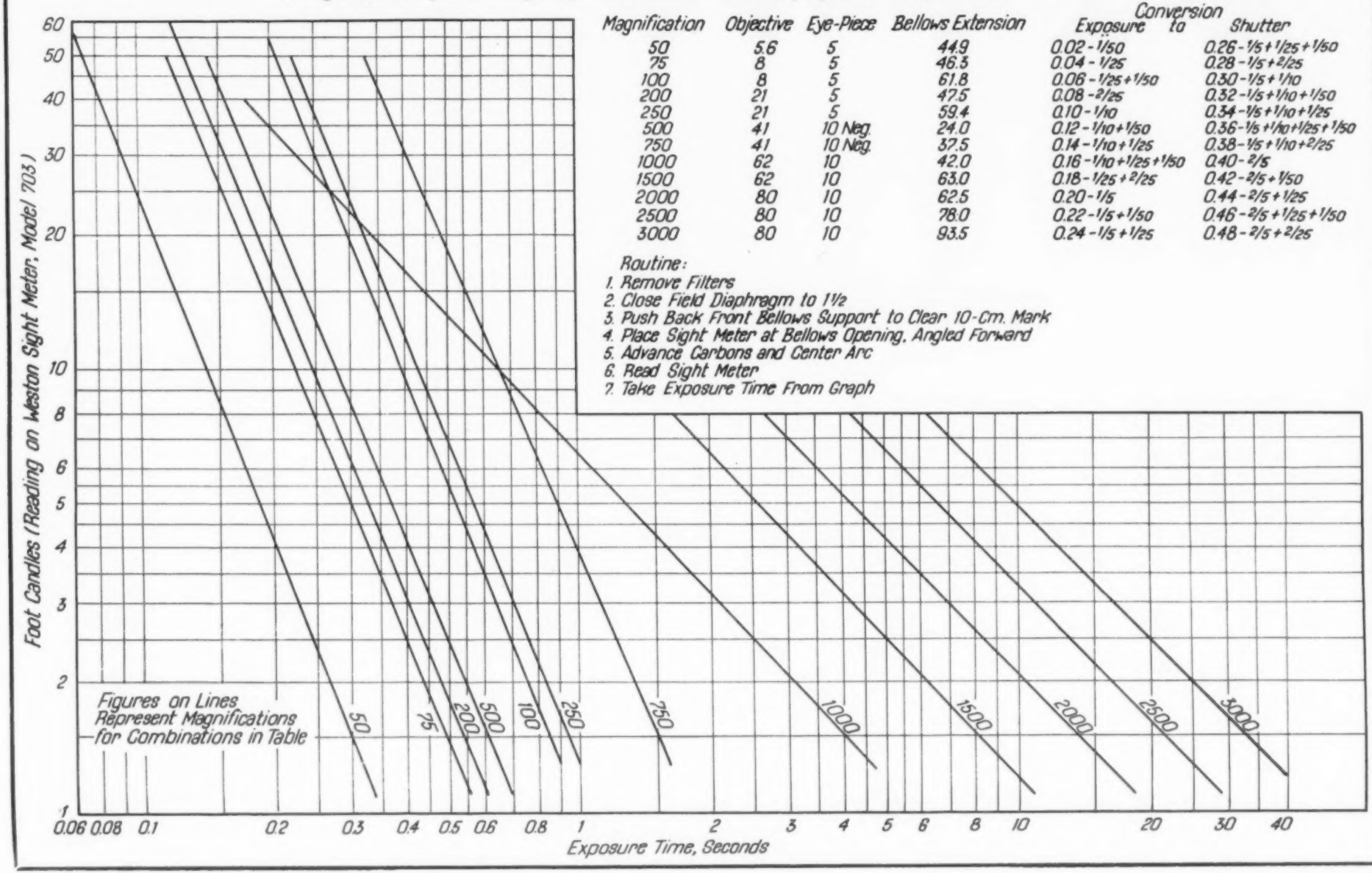
Using carbon arc, yellow and green filters, Wratten & Wainwright plates, developed 5 min. in DK-50

By Anton L. Schaeffler

Magnification	Objective	Eye-Piece	Bellows Extension	Conversion Exposure	to Shutter
50	5.6	5	44.9	0.02 - 1/50	0.26 - 1/5 + 1/25 + 1/50
75	8	5	46.3	0.04 - 1/25	0.28 - 1/5 + 2/25
100	8	5	61.8	0.06 - 1/25 + 1/50	0.30 - 1/5 + 1/10
200	21	5	47.5	0.08 - 2/25	0.32 - 1/5 + 1/10 + 1/50
250	21	5	59.4	0.10 - 1/10	0.34 - 1/5 + 1/10 + 1/25
500	41	10 Neg.	24.0	0.12 - 1/10 + 1/50	0.36 - 1/5 + 1/10 + 1/25 + 1/50
750	41	10 Neg.	37.5	0.14 - 1/10 + 1/25	0.38 - 1/5 + 1/10 + 2/25
1000	62	10	42.0	0.16 - 1/10 + 1/25 + 1/50	0.40 - 2/5
1500	62	10	63.0	0.18 - 1/25 + 2/25	0.42 - 2/5 + 1/50
2000	80	10	62.5	0.20 - 1/5	0.44 - 2/5 + 1/25
2500	80	10	78.0	0.22 - 1/5 + 1/50	0.46 - 2/5 + 1/25 + 1/50
3000	80	10	93.5	0.24 - 1/5 + 1/25	0.48 - 2/5 + 2/25

Routine:

1. Remove Filters
2. Close Field Diaphragm to 1½
3. Push Back Front Bellows Support to Clear 10-Cm. Mark
4. Place Sight Meter at Bellows Opening, Angled Forward
5. Advance Carbons and Center Arc
6. Read Sight Meter
7. Take Exposure Time From Graph



Metal Progress Data Sheet; November 1946, Page 1118